

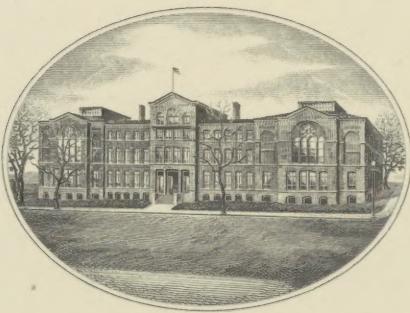


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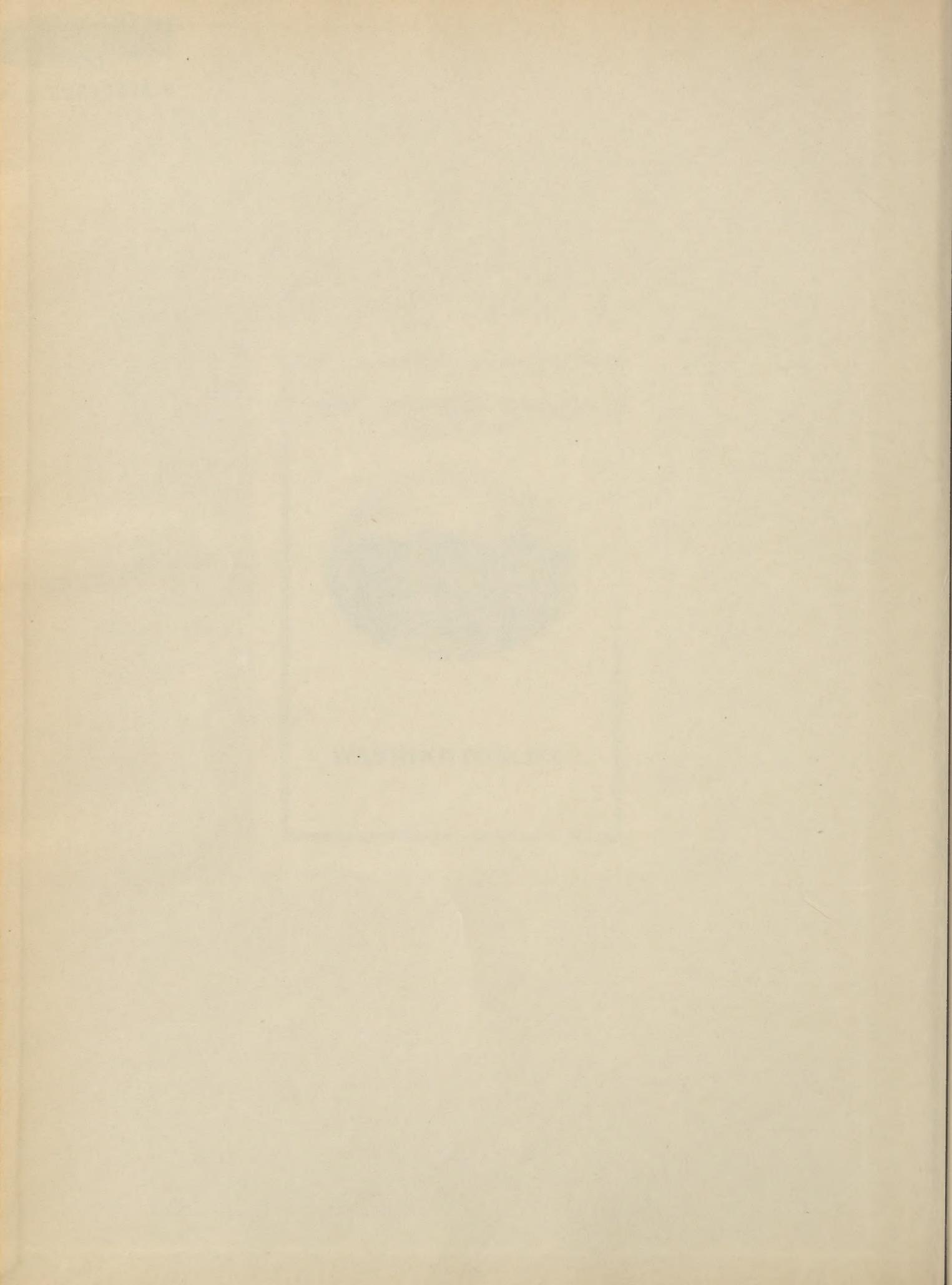
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Responsible Investigators: Walter M. Boothby, E. J. Baldes and C. F. Code  
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\* Before going into military service.

\*\* The major reports of the Acceleration Laboratory will be published shortly in the monograph entitled "The Effects of Acceleration and Their Amelioration," edited by the Subcommittee on Acceleration of the Committee on Aviation Medicine of the National Research Council.

\*\*\* From the Department of Aeronautical Engineering, University of Minnesota.

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MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT

to

ARMY AIR FORCES MATERIEL COMMAND  
Under Contract No. W535 ac-25829

SUBJECT: Vital capacity, complemental and reserve air, in positive pressure breathing, with and without corresponding counter pressure.

SERIAL REPORT: Series A, No. 5.

DATE: September 16, 1943

A. Purpose.

To confirm and extend the observations of Gagge and others on the effects of positive pressure breathing, with and without a corresponding counter pressure, on the relation of the tidal air to the vital capacity.

B. Factual Data.

1. A series of experiments were performed in the low pressure chamber at ground level and at simulated altitudes of ten, twenty, thirty and forty thousand feet. In each experimental flight recordings of the tidal air and vital capacity were made in the following order:

- a. Normal control without positive pressure
- b. Positive pressure breathing with a corresponding counter pressure
- c. Positive pressure breathing without counter pressure
- d. Return to normal control without positive pressure

A positive pressure of twenty centimeters of water was used.

2. The system, illustrated in Fig. I, was used to measure respiratory volumes. A closed circuit metabolism apparatus, (Boothby-Collins) was placed in the air lock, connected through one valve opening in the door of the main chamber to a Bulbulian pressure breathing mask worn by the subject. The line to the mask was fitted with inspiratory and expiratory valves and soda lime container in the expiratory side as illustrated. Through another valve, the lock was also connected to the counter pressure jacket. Positive pressure was obtained by adjusting the lock to a pressure 20 cm. H<sub>2</sub>O higher than that of the main chamber, the pressure being measured by water manometer as shown, and another near the operator on the outside of the chamber.

It should be noted that this method gives a more nearly constant pressure at all times than any form of pressure breathing in actual use. This method therefore establishes only a base line from which the results of other methods will obviously diverge because pressure in mask and counter pressure in jacket will not remain as constant. During the course of rapid maximal inspiration and expiration the maximal pressure fluctuation noted was 1.5 cm. H<sub>2</sub>O. With normal breathing, pressure fluctuations were less than 0.5 cm. H<sub>2</sub>O.

3. The results of fourteen experiments on three subjects (sitting) are included in this report, (Fig. II-VI inc.).

The measurements for the vital capacity were made in the manner illustrated in Fig. VII. To secure the correct vital capacity, i.e., complemental air plus reserve air, it was necessary to measure perpendicular to the tidal air base line in order to avoid error of slope of base line due to oxygen consumption. It can be seen in the diagram in Fig. VII that this factor becomes an appreciable one at forty thousand feet, after appropriate altitude corrections are properly made for barometric pressure, vapor pressure of water and body temperature at 37° C., as compared to that shown for the ground level. These measurements will then compare with the measurements for the complemental and reserve air as illustrated in diagram of subdivisions of lung air where the resting respiratory level is horizontal and the factor of oxygen consumption and altitude effects are eliminated and a respiratory quotient and alveolar pressure ratio of unity is assumed.

4. The results of the experiments with positive pressure breathing, with and without corresponding counter pressure, are illustrated in Fig. VIII. Complemental air and reserve air are expressed in terms of per cent of measured vital capacity. The vital capacity is represented as 100 per cent since it remains essentially the same at the various altitudes when appropriate corrections are made for barometric pressure, temperature, water vapor and also for carbon dioxide (Fig. IX) when absorption by soda lime takes place; this last correction has, because of its small size at ground level, heretofore been neglected. Experiment XIV shows that it is a very considerable correction at 40,000 feet.

5. The graphic presentations of the changes in complemental air in Fig. VIII illustrate the marked difference between the (a) complemental air with positive pressure breathing and corresponding counter pressure as compared to (b) the complemental air without counter pressure. This difference is shown in the following table. Complemental air (in per cent of vital capacity) of the three subjects is averaged at each altitude.

TABLE I

COMPLEMENTAL AIR, (PER CENT OF VITAL CAPACITY)  
Averages of three subjects for each altitude and for all altitudes

Elevation	Normal control without pres. breathing	Pres. breathing with counter pressure	Pres. breathing without counter pressure	Reduction in complemental air
	Per cent	Per cent	Per cent	Percentage Points
1,000 ft.*	64	56	38	18
10,000 ft.	65	57	42	15
20,000 ft.	64	65	43	12
30,000 ft.	64	64	43	21
40,000 ft.	72	63	38	24
	66	61	41	20

\* Ground

This table in addition to Fig. VIII shows that altitude apparently does not affect the complemental and reserve air relationship to the vital capacity and that the effect of positive pressure breathing on this relationship is approximately the same at altitudes as it is on the ground within the limitations of experimental error.

6. After appropriate corrections were made for barometric pressure, temperature and water vapor (volumes brought to ambient barometric pressure, 37° C., and saturated to 47 mm. Hg water vapor) it was noted that at 40,000 feet there was appreciable error in the measurement of the vital capacity due to the absorption of carbon dioxide when using an ordinary basal metabolism apparatus containing soda lime on the assumption that the respiratory quotient or the alveolar pressure ratio is unity in the air which has been expired to obtain the volume of the vital capacity. Experiment No. XIV was done to correct this error due to the carbon dioxide absorption (Fig. XI); at altitudes the per cent of carbon dioxide is very high in the alveolar air (30 to 40 per cent) and a large amount of this is included in the air expired from a vital capacity measured.

a. A by-pass tube was placed around the soda lime container and the vital capacities were then recorded with and without the soda lime in the system. The results obtained are shown on the following table. The last column shows the approximate correction to be added to the volume of the vital capacity if it is measured in an ordinary basal metabolism apparatus with absorption of carbon dioxide by soda lime.

TABLE II

VITAL CAPACITY AT EACH ALTITUDE WITH AND WITHOUT SODA LIME  
Using closed circuit basal metabolism apparatus that absorbs  
carbon dioxide with soda lime.

Subject: H.A.R.	Apparent vital capacity with soda lime	True vital capacity without soda lime	Approximate correc-
			tion to obtain true vital capacity
1,000 ft.*	4.83	4.93	+ 2
10,000 ft.	4.80	4.85	+ 1
20,000 ft.	4.63	4.89	+ 6
30,000 ft.	4.39	4.91	+12
40,000 ft.	3.94	4.78	+21
<u>4.87, Average V.C.</u>			

\* Ground

b. The results of making the above correction for carbon dioxide absorption in series of experiments on same subject (H.A.R.) as in Table II is shown in the following table:

TABLE III

Subject: H.A.R.	Apparent vital capacity	True vital capacity	Liters, B. 37° C. Sat.
Ground	4.71	4.80	
10,000 ft.	4.52	4.57	
20,000 ft.	4.50	4.77	
30,000 ft.	4.20	4.70	
40,000 ft.	3.80	4.69	
<u>4.69, Average cor- rected V.C.</u>			

c. When apparent vital capacities are corrected for carbon dioxide absorption with the correction percentage (shown in Table II) the average of the calculated true vital capacities (4.69 liters, Table III) are shown to be approximately the same as for those obtained when no soda lime is used in the system (4.87 liters, Table II), these results being within the limits of variation in vital capacities of the same individual.

d. Further studies are being made on the effect of absorption of carbon dioxide when an ordinary basal metabolism apparatus containing soda lime is used for measurement of the vital capacity.

C. Conclusions.

When the positive pressure is maintained at a nearly constant level at ground and at altitude, positive pressure breathing with a corresponding counter pressure gives a more nearly normal relation of complementary to reserve air than does pressure breathing without counter pressure. This further confirms the original observations of Gagge which were partially corroborated by Fenn, Barach and others.

D. Acknowledgement.

This was carried out under the direction of Dr. Walter M. Boothby and Dr. H. F. Helmholtz, Jr. We wish to express our thanks for the technical help of the non-professional staff.

Prepared by Harold A. Robinson, Major, M.C.

Francis J. Robinson, M.D.

Approved and  
forwarded by Walter M. Boothby, M. D.

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## MAYO AERO MEDICAL UNIT

EXPERIMENTS I-II-III

GROUND LEVEL

Volumes in liters, B. 37° C. Sat.

		V.C.	C.A.	T.A.	R.A.	
			%V.C.			%V.C.
H.C.	A	3.13	1.75	.56	.70	1.38 .44
		3.30	1.88	.57	.70	1.42 .43
Cor. Bar. 727 mm. Hg	B	3.08	1.70	.55	1.05	1.38 .45
		2.72*	1.84	.68	1.10	.88 .32
Temp. 24.0° C.	C	3.22	.97	.30	.74	2.25 .70
		3.09	.97	.31	.74	2.12 .69
	D	3.35	1.88	.56	.70	1.47 .44
		3.27	1.94	.59	.74	1.33 .41
H.A.R.	A	4.63	3.12	.67	1.02	1.51 .33
		4.60	3.18	.69	1.02	1.42 .31
Cor. Bar. 727 mm. Hg	B	4.65	2.58	.55	.97	2.07 .45
		4.79	2.72	.57	.97	2.07 .43
Temp. 24.0° C.	C	4.77	1.79	.38	.88	2.98 .62
		4.69	1.65	.35	.88	3.04 .65
	D	4.74	3.09	.65	.84	1.65 .35
		4.80	3.23	.67	.84	1.57 .33
L.B.	A	5.84	3.72	.64	.69	2.12 .36
		5.70	3.77	.66	.65	1.93 .34
Cor. Bar. 736 mm. Hg	B	5.56	3.22	.58	.65	2.34 .42
		5.65	3.31	.59	.65	2.34 .41
Temp. 24.0° C.	C	5.61	2.53	.45	1.01	3.08 .55
		5.61	2.57	.46	1.07	3.04 .54
	D	5.89	3.63	.62	.55	2.26 .38

V.C. - Vital Capacity

T.A. - Tidal Air

C.A. - Complemental Air

R.A. - Reserve Air

A - Normal control without pressure breathing.

B - Positive pressure breathing with corresponding counter pressure.

C - Positive pressure breathing with no counter pressure.

D - Return normal control without pressure breathing.

\* Incomplete vital capacity

Maj. Harold A. Robinson, M.C.

September 1943

Group 6 B-1

Appendix  
Table I.

MAYO AERO MEDICAL UNIT

EXPERIMENTS IV-V-VI

10,000 FOOT LEVEL

Volumes in liters, B. 37° C. Sat.

		V.C.	C.A.	T.A.	R.A.	%V.C.	
H.C.	A	3.19	1.85	.58	.65	1.34	.42
		3.21	1.81	.56	.60	1.40	.44
Cor. Bar. 522.9 mm., Hg	B	2.88	1.90	.66	1.25	.98	.34
		2.59*	1.85	.71	1.22	.74	.29
Temp. 25.0° C.	C	3.03	1.22	.40	1.11	1.81	.60
		2.79	1.16	.42	1.11	1.63	.58
	D	3.28	1.85	.56	.65	1.43	.44
		3.24	1.90	.59	.71	1.34	.41
H.A.R.	A	4.23	3.01	.71	.83	1.22	.29
		4.50	3.25	.72	.89	1.25	.28
Cor. Bar 522.9 mm., Hg	B	4.55	2.70	.59	.98	1.85	.41
		4.50	2.50	.56	.89	2.00	.44
Temp. 25.0° C.	C	4.41	1.85	.42	.89	2.56	.58
		4.55	2.14	.47	.83	2.41	.53
	D	4.73	3.30	.70	1.03	1.43	.30
		4.73	3.30	.70	.98	1.43	.30
L.B.	A	5.68	3.63	.64	.83	2.05	.36
		5.93	3.75	.63	.78	2.18	.37
Cor. Bar. 522.9 mm., Hg	B	5.71	2.92	.51	.89	2.79	.49
		5.81	3.07	.53	.93	2.74	.47
Temp. 25.0° C.	C	5.89	2.59	.44	1.03	3.30	.56
		5.60	2.41	.43	1.03	3.19	.57
	D	5.77	3.63	.63	.83	2.14	.37
		5.57	3.52	.63	.83	2.05	.36

V.C. - Vital Capacity

T.A. - Tidal Air

C.A. - Complemental Air

R.A. - Reserve Air

A - Normal control without pressure breathing.

B - Positive pressure breathing with corresponding counter pressure.

C - Positive pressure breathing with no counter pressure.

D - Return normal control without pressure breathing.

\* Incomplete vital capacity.

Group 6 B-2

Maj. Harold A. Robinson, M.C.  
September 1943

Appendix  
Table II

MAYO AERO MEDICAL UNIT

EXPERIMENTS VII-VIII-IX

20,000 foot level

Volumes in liters, B. 37° C. Sat.

		V.C.	C.A.	T.A.	R.A.	%V.C.
			%V.C.			%V.C.
H.C. Cor. Bar. 352 mm. Hg Temp. 24.0° C.	A	3.23	1.84	.57	.57	1.39
		3.17	1.78	.56	.57	1.39
	B	2.97	2.29	.77	1.08	.68
		3.02	2.26	.75	1.02	.76
	C	2.83	1.33	.47	1.10	1.50
		2.83	1.30	.46	1.10	1.53
	D	3.14	1.64	.52	.62	1.50
		3.12	1.73	.55	.62	1.39
H.A.R. Cor. Bar. 352 mm. Hg Temp. 24.0° C.	A	4.42	3.23	.73	.76	1.19
		4.42	3.26	.74	.82	1.16
	B	4.50	2.83	.63	.88	1.67
		4.56	2.97	.65	.88	1.59
	C	4.47	2.01	.45	.88	2.46
		4.56	2.15	.47	.82	2.41
	D	4.55	3.11	.68	.91	1.44
		4.50	3.11	.69	.91	1.39
L.B. Cor. Bar. 352.2 mm. Hg Temp. 24.0° C.	A	5.88	3.73	.63	.76	2.15
		5.88	3.73	.63	.76	2.15
	B	5.80	3.11	.54	.88	2.69
		5.91	3.31	.56	.91	2.60
	C	5.66	2.15	.38	1.10	3.51
		5.86	2.55	.44	1.10	3.31
	D	5.86	3.51	.60	.54	2.35
		6.02	3.73	.62	.48	2.29

V.C. - Vital Capacity

T.A. - Tidal Air

C.A. - Complemental Air

R.A. - Reserve Air

A - Normal control without pressure breathing.

B - Positive pressure breathing with corresponding counter pressure.

C - Positive pressure breathing with no counter pressure.

D - Return normal control without pressure breathing.

Maj. Harold A. Robinson, M.C.

September 1943

Group 6 B-3

Appendix

Table III

MAYO AERO MEDICAL UNIT

EXPERIMENTS X-XI-XII

30,000 FOOT LEVEL

Volumes in liters, B. 37° C. Sat.

	V.C.	C.A.		T.A.	R.A.	
			%V.C.			%V.C.
H.C. Cor. Bar. 228.4 mm. Hg Temp. 24.0° C.	A	3.14	1.57	.50	.57	1.57
		3.05	1.62	.53	.62	1.43
	B	2.91	1.86	.64	.67	1.05
		2.86	2.05	.72	.81	.81
	C	2.86	.67*	.23	.62	2.19
		2.86	1.24	.43	.90	1.62
	D	3.14	1.76	.56	.38	1.38
		3.00	1.76	.59	.38	1.24
H.A.R. Cor. Bar. 228.4 mm. Hg Temp. 24.0° C.	A	4.14	3.24	.78	.81	.90
		4.14	3.24	.78	.81	.90
	B	4.33	2.52	.58	.86	1.81
		4.33	2.52	.58	.90	1.81
	C	4.19	1.76	.42	.86	2.43
		4.14	1.62	.39	.76	2.52
	D	4.14	2.81	.68	.86	1.33
		4.14	2.95	.71	.86	1.19
L.B. Cor. Bar. 228.4 mm. Hg Temp. 24.0° C.	A	5.48	3.62	.66	.62	1.86
		5.66	3.95	.70	.62	1.71
	B	5.19	3.14	.61	.71	2.05
		5.24	3.24	.62	.67	2.00
	C	5.43	2.43	.45	.90	3.00
		5.57	2.76	.50	.81	2.81
	D	5.33	3.43	.64	.67	1.90
		5.47	3.76	.69	.67	1.71

V.C. - Vital Capacity

T.A. - Tidal Air

C.A. - Complemental Air

R.A. - Reserve Air

A - Normal control without pressure breathing.

B - Positive pressure breathing with corresponding counter pressure.

C - Positive pressure breathing with no counter pressure.

D - Return normal control without pressure breathing.

\* Incorrect determination due to change in resting level of tidal air caused by mask leak.

Group 6 B-4

Maj. Harold A. Robinson, M.C.  
September 1943

## MAYO AERO MEDICAL UNIT

EXPERIMENT XIII40,000 FOOT LEVEL

Volumes in liters, B. 37° C. Sat.

		V.C.	C.A.	T.A.	R.A.	%V.C.	
			%V.C.				
H.A.R.	A	3.62	2.60	.72	.93	1.02	.28
		3.71	2.60	.70	.93	1.11	.30
Cor. Bar. 140 mm. Hg	B	3.80	2.41	.63	.93	1.39	.37
		3.90	2.41	.62	.84	1.49	.38
Temp. 23.0° C.	C	3.90	1.49	.38	.84	2.41	.62
		4.08	1.67	.41	.93	2.41	.59
	D	3.81	2.60	.68	.84	1.21	.32
		3.63	2.41	.66	.84	1.21	.33

V.C. - Vital Capacity

T.A. - Tidal Air

C.A. - Complemental Air

R.A. - Reserve Air

A - Normal control without pressure breathing.

B - Positive pressure breathing with corresponding counter pressure.

C - Positive pressure breathing with no counter pressure.

D - Return normal control without pressure breathing.

EXPERIMENT XIV

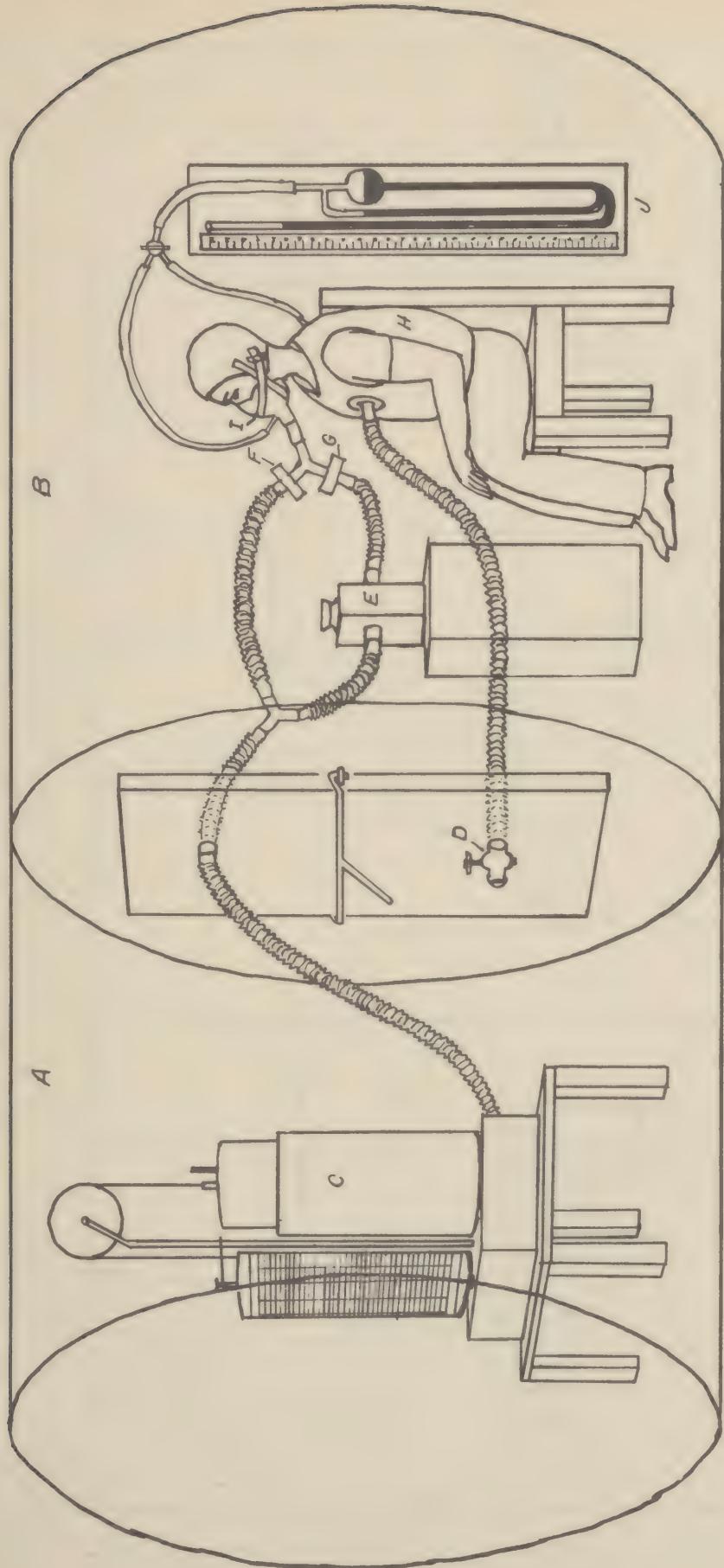
Subject: H.A.R.		Volumes in liters, B. 37° C. Sat.		
Altitude	Cor. Bar.	Temp.	Apparent Vit. Cap.	True Vit. Cap.
1,000 ft.	734.6	22° C.	4.83	4.93
10,000 ft.	520.0	21° C.	4.80	4.85
20,000 ft.	351.2	20° C.	4.63	4.89
30,000 ft.	228.2	20° C.	4.39	4.91
40,000 ft.	139.1	20° C.	3.94	4.78

Apparent Vital Capacity - With soda lime in circuit.

True Vital Capacity - Without soda lime in circuit.

Group 6 B-5

Maj. Harold A. Robinson, M.C.  
September 1943



SKETCH OF APPARATUS USED TO DETERMINE EFFECTS OF  
POSITIVE PRESSURE WITH AND WITHOUT CORRESPONDING COUNTER PRESSURE.  
PRESSURE, IN WATER CHAMBERS, OBTAINED BY DIFFERENTIAL IN THE TWO CHAMBERS

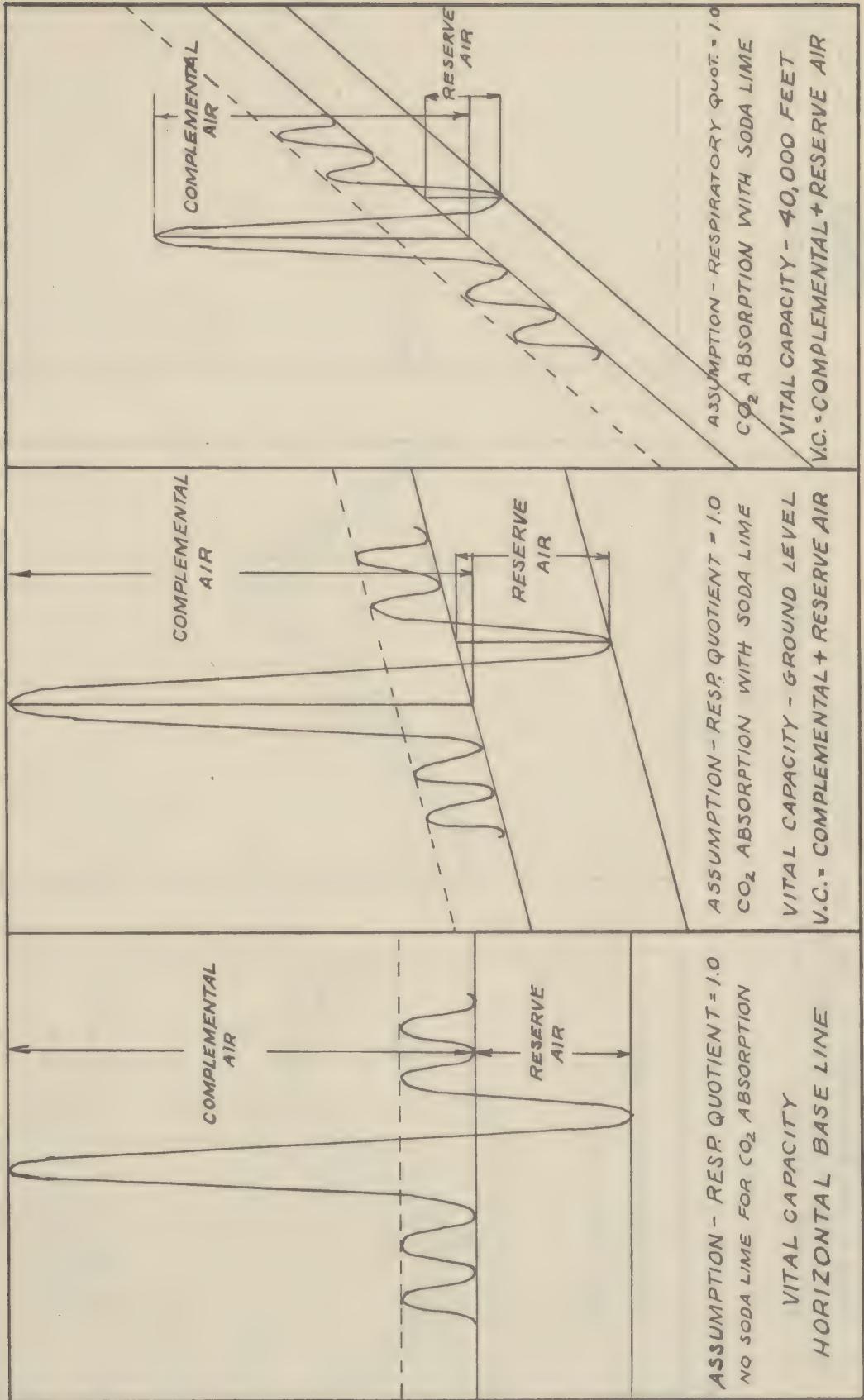
- A. AIR LOCK
- B. MAIN CHAMBER
- C. BOOTHBY-COLLINS SPIROMETER
- D. VALVE TO RELEASE COUNTER PRESSURE
- E. SODA LIME
- F. INSPIRATORY VALVE
- G. EXPIRATORY VALVE
- H. PRESSURE BREATHING JACKET
- I. PRESSURE BREATHING MASK
- J. WATER MANOMETER

XXX-2 a

MAJ. H.A. ROBINSON, MC SEPT 1943  
F.J. ROBINSON, M.D.

MAYO AERO MEDICAL UNIT

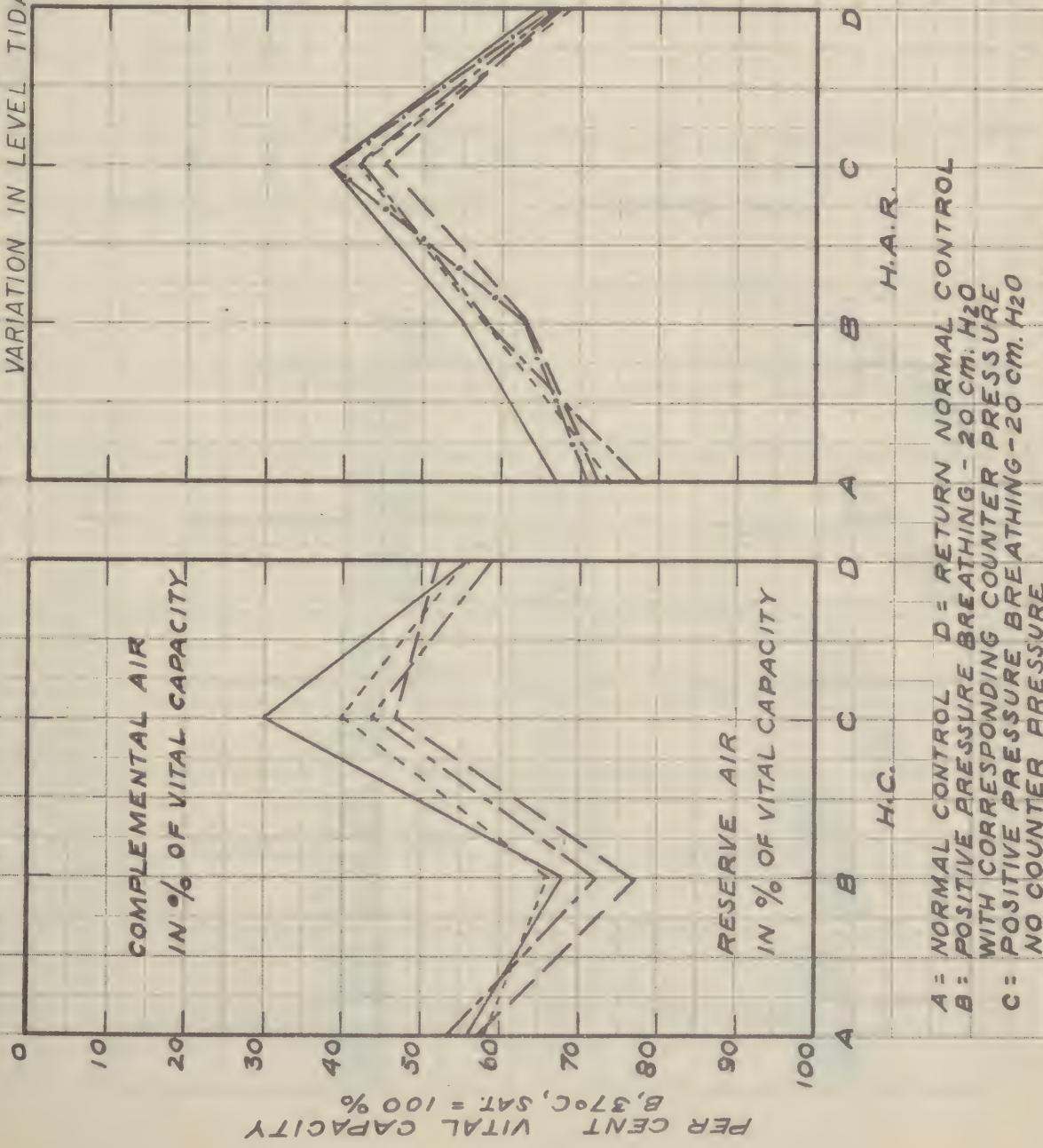
VITAL CAPACITY  
METHOD OF MEASUREMENT



XIX - 2 b

APPENDIX FIG. II

EFFECTS OF POSITIVE PRESSURE BREATHING ON  
RELATION OF COMPLEMENTAL AND RESERVE AIR  
IN PER CENT OF VITAL CAPACITY AT ALTITUDES  
VARIATION IN LEVEL TIDAL AIR



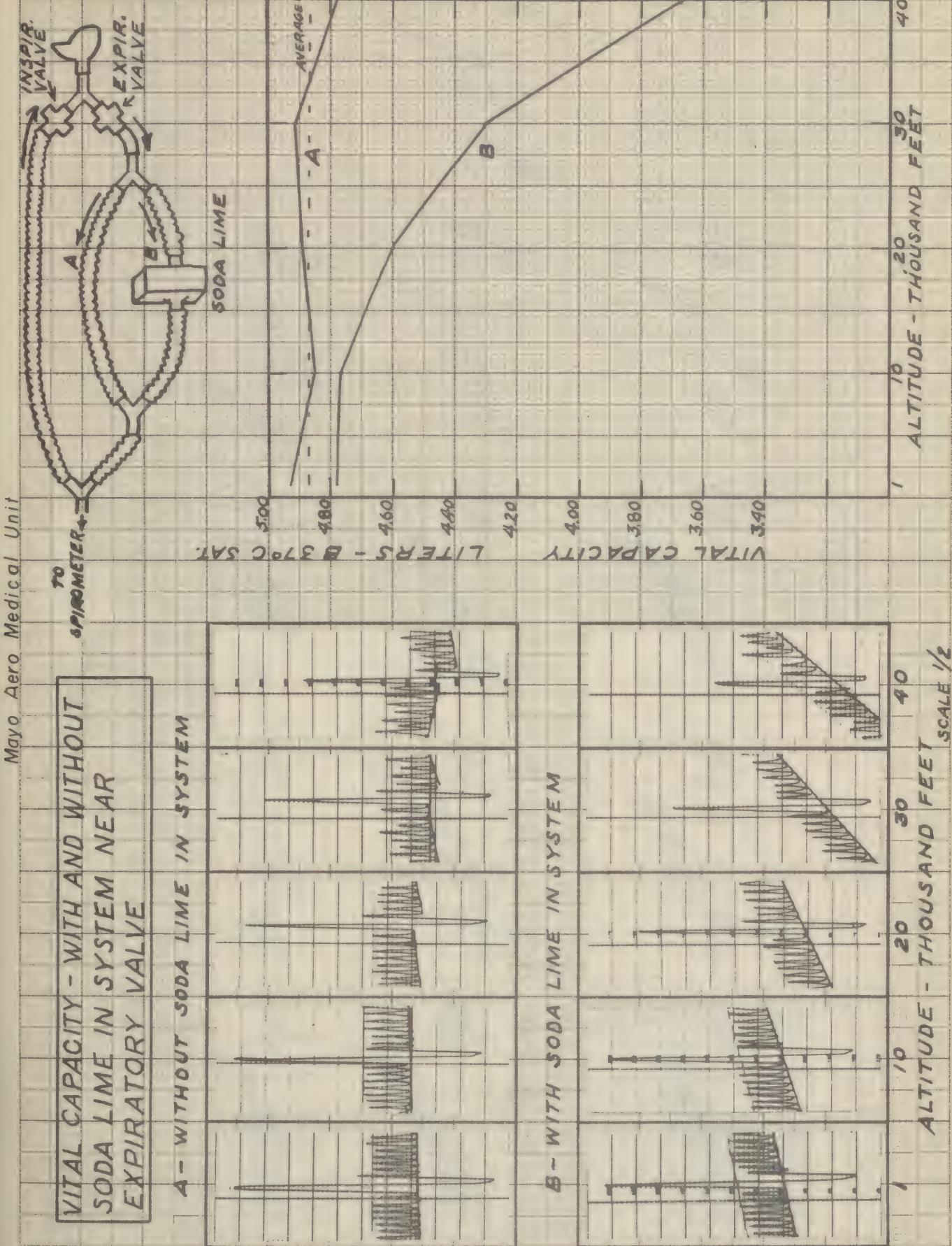
**A:** NORMAL CONTROL      **D:** RETURN NORMAL CONTROL  
**B:** POSITIVE PRESSURE BREATHING - 20 CM<sub>3</sub> H<sub>2</sub>O  
 WITH CORRESPONDING COUNTER PRESSURE  
**C:** POSITIVE PRESSURE BREATHING - 20 CM<sub>3</sub> H<sub>2</sub>O  
 NO COUNTER PRESSURE

*GROUND*  
10,000 ft.  
20,000 " "  
30,000 "  
40,000 "

MAU. H.A. ROBINSON, MC SEPT. 43 HR

APPENDIX FIG. III

Mayo Aero Medical Unit



XIX- 2 d

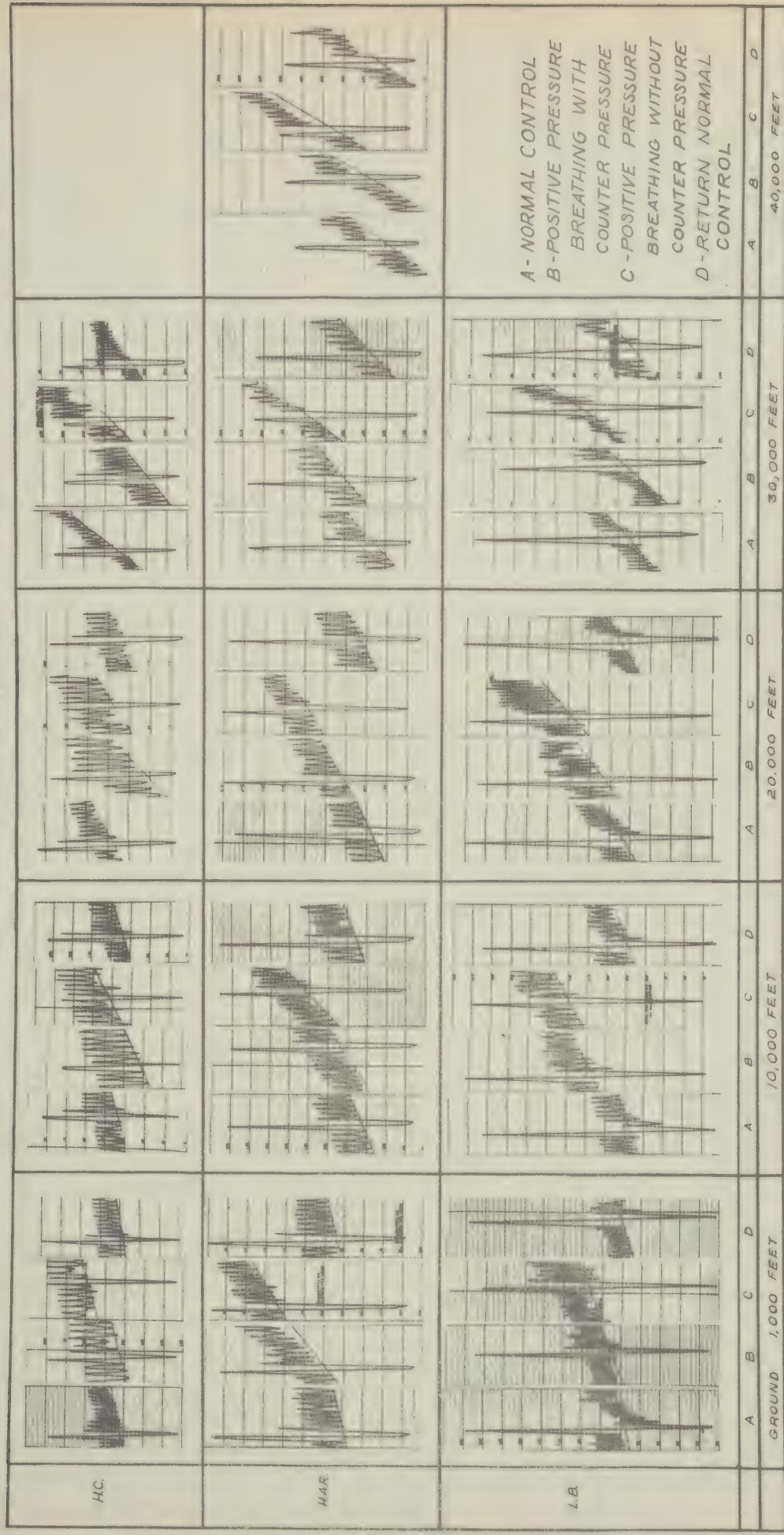
F/G. IV

APPEND

MAJ H.A. ROBINSON MC  
F.J. ROBINSON, MD  
SEPT /043

MAYO AERO MEDICAL UNIT

EFFECTS OF POSITIVE PRESSURE BREATHING, WITH AND WITHOUT COUNTER PRESSURE  
ON SUBDIVISIONS OF LUNG AIR AT GROUND LEVEL AND AT ALTITUDES.



XIX-2e

APPENDIX FIG V

MAU H.A. ROBINSON, MC SEPT. 1943  
F.J. ROBINSON, MA



ME-2

MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT  
to  
ARMY AIR FORCES MATERIEL COMMAND  
Under Contract No. W535 ac-25829

SUBJECT: Summary of data on the volumetric analysis of pure atmospheric air.

SERIAL REPORT: Series A, No. 6

DATE: October 7, 1943

A. This report is in response to a verbal request by Lt. Colonel W. Randolph Lovelace, II, for a summary of the more important literature on the analysis of outdoor air.

B. (1) Haldane's figures on his own carefully calibrated gas analysis apparatus were on four samples as follows:

	Oxygen	Carbon Dioxide
No. 1	20.930%	.025%
No. 2	20.926	.030
No. 3	20.931	.035
No. 4	20.924	.030
Mean	20.928%	.030%

The data are given on page 44 in his book, "Methods of Air Analysis," published by Charles Griffin and Company, Limited, London (1912). In this book is described the apparatus and technics (from which slight modifications have been made) which is in most general use in physiological laboratories where considerable studies are made on respiratory and metabolic problems.

(2) The series of analyses on outdoor air carried out in our laboratory were reported by Boothby and Sandiford in the American Journal of Physiology, Volume 55, No. 2, March, 1921. From this report is taken the following abstract: "The average composition of outdoor air determined from this series of 974 analyses is as follows; carbon dioxide 0.036 per cent; oxygen 20.927 per cent; nitrogen and other non-absorbable gases 79.037 per cent . . . . Throughout the year the carbon dioxide remains essentially unchanged and shows no seasonal variation. However, the weekly average of the oxygen per cent lies between 20.930 and 20.938 per cent during the latter part of January and the months of February, March, April and the early part of May; during the remainder of the year the weekly average lies between 20.918 and 20.930 per cent."

Although our grand average was 20.930 per cent on 974 air analyses, we have felt that possibly the more nearly correct figure was 20.94 per cent because the most frequent chance of technical error in a large series is probably greater on the low side than on the high side.

(3) Carpenter in the Journal of the American Chemical Society, 59:358, (1937) on "The Constancy of the Atmosphere with Respect to Carbon Dioxide and Oxygen Content" presents a series of tables containing data which show that the average values over several years for carbon dioxide = 0.031 volumes per cent and for oxygen = 20.939 volumes per cent. This study of Carpenter's on the volumetric analysis of pure outdoor air is the most carefully carried out and therefore the most authentic investigation of the subject made in this country.

Carpenter in his book on "Tables, Factors and Formulas for Computing Respiratory Exchange and Biological Transformation of Energy," third edition, published by the Carnegie Institution of Washington, Washington, D. C., 1939, in various important tables (tables 11 and 37) uses the following values for outdoor air: oxygen = 20.940 per cent; carbon dioxide = 0.030 per cent; and atmospheric nitrogen = 79.030 per cent. (The term "atmospheric nitrogen" is used to include argon, 0.9 per cent, and other inert gases.)

(4) Humphrey in his book, "Physics of the Air," third edition, 1940, page 67 and 68, quotes F. A. Peneth (Quart. J. Roy. Meteorol. Soc., 63:433, 1937) and gives the volume percentages in dry atmospheric air at the surface of the earth as follows:

<u>Element</u>	<u>Volumes</u>
	<u>Per cent</u>
Nitrogen (chem.)	78.09
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.03
Neon	0.0018
Helium	0.00053
Krypton	0.0001

Humphrey also quotes Hann and Suring's figures from the fifth edition of their book, "Lehrbuch der Meteorologie," for nitrogen 78.08 and for oxygen 20.95 volumes per cent.

(5) Tables 692 and 693 on page 558 of Smithsonian Physical Tables, eighth edition, 1934, are percentages based upon moist air and separates argon and other inert gases from nitrogen. Therefore such tables are not applicable to standard volumetric methods of air analysis used in physiology where the percentages apply directly to the basis of dry air and includes under the term nitrogen (atm.) other inert gases. It is to be noted that in Table 127 on Density of Gases that the specific gravity on the basis of air = 1 refers to carbon dioxide-free air.

C. Summary. From the above review of the literature it seems best to adopt for the volumetric standard of outdoor dry pure air in this country when using a calibrated Haldane or Carpenter type of gas analyzer the following values used by Carpenter in "Tables, Factors and Formulas for Computing Respiratory Exchange and Biological Transformation of Energy":

$$\begin{aligned} \text{Carbon dioxide} &= 0.030 \text{ volumes per cent} \\ \text{Oxygen} &= 20.940 \quad " \quad " \quad " \\ \text{Nitrogen (atm.)} &= 79.030 \quad " \quad " \quad " \end{aligned}$$



W.M.

MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT

to

ARMY AIR FORCES MATERIEL COMMAND  
Under Contract No. W535 ac-25829

SUBJECT: Review of "A Study of Cerebral Physiology at High Altitude" by Melvin W. Thorner, Major, M.C., Report Number 2, Project Number 60, from the Army Air Forces School of Aviation Medicine, Randolph Field, made at the request of Chief, Aero Medical Laboratory, Engineering Division, Wright Field.

SERIAL REPORT: Series A, No. 7

DATE: April 5, 1944

1. The usual discussion and arguments in favor of using mixtures of carbon dioxide and oxygen at high altitudes are restated by the author.

2. The presentation of new evidence begins with the last paragraph on page 3 and is continued on pages 4 and 5.

a. The most important part of the evidence is contained in the first paragraph beginning on page 4 in which they state that electroencephalograms gave positive evidence of improvement after certain signs (attributed to anoxia) had developed at around 35,000 to 40,000 feet which disappeared when a shift was made from pure oxygen to carbon dioxide-oxygen mixtures. A further ascent of several thousand feet was made before these objective signs in the electroencephalogram reappeared. It would be advisable for the authors to present this part of the experimental data in greater detail and if possible to run another series of experiments.

b. In Table I are presented data of hemoglobin saturation with oxygen using a Millikan oximeter with the subject breathing pure oxygen contrasted to the concentration obtained with a subject breathing 10 per cent carbon dioxide and 90 per cent oxygen at various altitudes. Although the author does not call attention to it, there is some important evidence in the top four determinations in the table. Two of these determinations were at 46,000, one at 44,000 and the first of those at 38,000 feet. In all four the percentage saturation of hemoglobin was slightly higher on 100 per cent oxygen than on 10 per cent carbon dioxide and 90 per cent oxygen.

It is possible that, for example, in subject V.I. at 46,000 feet the 78 per cent of saturation of hemoglobin when breathing oxygen as contrasted with the 76 per cent when breathing a mixture of carbon dioxide and oxygen may indicate that in the latter case washing out of carbon dioxide was prevented and that in the former on pure oxygen there had been sufficient hyperventilation so that the percentage saturation was slightly increased as a result of a small shift in the dissociation curve to the left.

Although these differences are so slight as not to be of any very great significance, however, they are definitely greater than in nearly all the remaining determinations.

3. Interpretation of Data Presented. Accepting the experimental evidence in the paper as having at least some significance, the data could be interpreted as

possibly suggesting that at high altitudes the use of 10 per cent carbon dioxide and 90 per cent oxygen (administered apparently by the demand system) prevented the subject from hyperventilating and therefore prevented the superimposition of the ill effects of producing a moderate degree of acapnia on top of a moderate degree of anoxia.

4. In 1938 in a paper by Boothby and Lovelace on "Oxygen in Aviation" it was pointed out that the use of a reservoir rebreathing bag in the oxygen supply system would make it difficult for an aviator to efficiently hyperventilate and thus materially lower his alveolar or blood carbon dioxide. They further pointed out, "The presence of a slight amount of carbon dioxide (as a result of the reservoir rebreathing bag) is an advantage in that it increases by about 50 per cent the respiratory minute volume, thereby increasing the alveolar pressure of oxygen and tending to prevent a shallow and dangerous type of respiration. McFarland and Dill have reported experiments which indicate that, when 3 per cent carbon dioxide was introduced into the low pressure or low oxygen chamber at simulated altitudes of 17,000 and 20,000 feet, the simulated altitude was lowered by approximately 5,000 feet. However, we feel that it is unnecessary to have carbon dioxide and oxygen mixed in the cylinders, since the amount of rebreathing with the B.L.B. apparatus can be controlled by varying the number of ports left open."

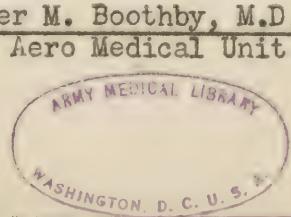
5. Subsequent experience has shown that trained aviators rarely seriously hyperventilate. For military purposes it has been considered impractical to furnish a separate and complicated system for the addition of carbon dioxide to inhaled oxygen supplied to the aviator in an airplane. The system to be safe must provide a considerable range in the quantity of carbon dioxide added because at high altitudes, around 40,000 feet, 10 per cent carbon dioxide will increase the partial pressure of carbon dioxide in the tracheal air mixture to about 9 mm. [(141 - 47) x 0.10]. A partial pressure of 9 or 10 mm. carbon dioxide can be readily breathed without discomfort and possibly in a few individuals with some advantage. However, 10 per cent carbon dioxide at sea level would mean that the tracheal inspired air would contain around 70 mm. of carbon dioxide which of course no one can inhale for more than a few minutes. At 20,000 feet 10 per cent carbon dioxide would produce a partial pressure of carbon dioxide in the tracheal inspired air of around 30 mm. and would cause discomfort although it could be inspired for a considerable time.

6. Should the advantage of carbon dioxide in increasing the ceiling of the aviator be conclusively shown to be sufficient to make it of practical value, then carbon dioxide should be provided by the aviator himself and not from a tank. As pointed out in our report, Series A, No. 3, to the Army Air Forces Materiel Command under Contract No. W535ac-25829, November 20, 1942, (a copy of which is attached) we showed that an economizer bag attached to the oxygen demand system materially increases oxygen economy. The waste in the use of oxygen without the use of an economizer bag ranges from 50 to 75 per cent. When such an economizer bag is used washing out of carbon dioxide and the development of acapnia is likewise prevented. However, an economizer bag is one more complicating factor and probably therefore would also be impractical for military aviation.

7. Summary. The possible gain in elevation that can be obtained by the use of prepared carbon dioxide-oxygen mixtures is not sufficient to be of practical importance in military aviation.

Prepared by Walter M. Boothby, M.D.  
Mayo Aero Medical Unit

\* Journal of Aviation Medicine, Dec. 1938.



mc-4

ARMY AIR FORCES  
SCHOOL OF AVIATION MEDICINE  
RANDOLPH FIELD, TEXAS

Research Report

Project No. 60

Date 15 January 1944

Report No. 2

Expenditure order \_\_\_\_\_

1. Title: A Study of Cerebral Physiology at High Altitudes.
2. Object: To determine the functional adequacy of supplemental oxygen alone at 35,000 foot altitudes and above, and to determine the functional advisability of using carbon dioxide-oxygen mixtures.
3. Conclusions and Recommendations:
  - a. No evidence of decreased efficiency of cerebral activity at 35,000-45,000 foot altitudes was found when carbon dioxide was substituted for ten per cent of the oxygen in the supply mixture.
  - b. No evidence was found that there was any significant lowering of the hemoglobin oxygen saturation under the above conditions.
  - c. There was abundant clinical and electroencephalographic evidence that the altitude ceiling could be raised approximately 3,000-5,000 feet for periods of time approximating 30 minutes to 1 hour.
  - d. The tactical possibilities are discussed.

Report by:

MELVIN W. THORNER, Major M.C.

Approved:

ROBERT C. ANDERSON, Lt. Col. M.C.

Approved:

PAUL A. CAMPBELL, Lt. Col., M.C.

Approved:

EUGENE G. REINARTZ, Brig. Gen. USA  
Commandant

Recommended Classification:

Open:

Restricted:

Confidential:

Secret:

Discussion:

In three previous reports attention was given to the use of carbon dioxide and oxygen mixtures at altitudes. The first of these reports (1) contained some evidence derived from a study involving the use of ten per cent carbon dioxide and ninety per cent oxygen as a breathing mixture at altitudes varying from 35,000 to 45,000 feet. The electroencephalographic evidence indicated that a more efficient type of cerebral function occurred in this altitude bracket when carbon dioxide mixtures were used than when pure oxygen was used for breathing. In the second of these reports (2) a study was made of the changes which occur when the anoxia at 18,000 feet without supplementary oxygen, and of the changes in the electroencephalogram which occur at 45,000 feet with a demand system and one hundred per cent oxygen supply. During this study it was also evident that certain of the changes in the electroencephalogram induced by anoxia at altitudes could be reversed by the addition of carbon dioxide. In a third study (3) it was shown that the effects of a voluntarily increased ventilation rate upon the electroencephalogram were probably due to an induced alkalosis as these changes could be prevented by the use of a sufficient concentration of carbon dioxide in the inspired mixture at ground level. A recent paper (4) showed that many of the electroencephalographic effects of breathing low oxygen mixtures at ground level could be prevented for some period of time by the addition of carbon dioxide to the low oxygen mixtures. A striking finding in this paper indicated that the electroencephalogram may yield none of the electrical potential changes, which usually indicate the onset of unconsciousness due to anoxia, when carbon dioxide is added to the breathing mixture.

The use of carbon dioxide in breathing gas mixtures in relation to the purposes of military aviation may be considered from two main points of view. The first of these would be concerned with the effects of oxygen concentration and oxygen utilization in the body, and the second upon the effects of carbon dioxide itself. These are not two separate points of view, but have a certain amount of interdigitation. The arguments concerning the oxygen relationships during the inhalation of carbon dioxide mixtures may be considered in the following states or layers:

1. Partial pressure of oxygen in the inspired air or gas mixtures.
2. The alveolar oxygen tension.
3. The blood oxygen concentration.
4. The blood flow through the tissues.
5. The oxygen concentration of the body intercellular substrate.
6. Ability of the body cells to use the oxygen available in the intercellular substrate.

If these points be considered in order, the following evidence is available:

1. The partial pressure of oxygen in the inspired air at ground level is 158 mm. of mercury. General experience and more specific investigations have failed to receive any striking changes in efficiency when flying at altitudes up to 10,000 feet above ground level (5). This corresponds to a partial pressure of oxygen of 105 mm. of mercury. When the inspired gas consists of one hundred per cent oxygen, the oxygen tension in the inspired air is equivalent to that available at an altitude of 46,000 feet. This altitude is practically unobtainable with preservation of serviceable physiological integrity for any prolonged period of time except by the use of additional factors such as pressure breathing. The apparent discrepancy is probably due to alveolar factors such as the water vapor tension in the alveoli. The addition of carbon dioxide to the breathing mixtures used at higher altitudes

decreases the partial pressure of oxygen available at any given altitude and this must be regarded as a possible point against the use of carbon dioxide mixtures at altitudes. However, the blood hemoglobin saturation with oxygen as shown in Table I is not appreciably lowered at 38,000 feet or for some distance above by the substitution of ten per cent carbon dioxide-ninety per cent oxygen mixtures for one hundred per cent oxygen. While this situation would seem an odd way of paying Paul without robbing Peter, a small amount of calculation would reveal that it is only to be expected for the particular altitudes and concentrations concerned.

2. The alveolar oxygen tension at ground level is 101 mm. of mercury and that of carbon dioxide is approximately 40 mm. of mercury. The alveolar oxygen tension decreases during altitude ascents. During the ascent to higher altitudes a relative alkalosis has also been shown to occur (6). Here again on the basis of the available formulae for alveolar partial gas pressures it would not be expected that the addition of even large amounts of carbon dioxide would cut down the alveolar oxygen tension by any great amount. For example, it may be calculated that at 45,000 feet breathing a mixture of twenty-seven per cent carbon dioxide and seventy-three per cent oxygen in the alveolar oxygen tension is reduced by only eight per cent.

3. The blood oxygen content in terms of blood hemoglobin saturation is about ninety-five per cent at sea level breathing air. After the blood leaves the lungs it is conducted with little change in oxygen content to the capillaries. In the capillary bed the low oxygen tension in the tissues adds in the diffusion outward of plasma oxygen and the consequent dissociation of oxyhemoglobin into oxygen and reduced hemoglobin. When the blood  $\text{CO}_2$  is increased, dissociation of oxyhemoglobin is facilitated (the Bohr effect), and a steeper potential gradient from the blood plasma to the intercellular substrate may be produced. This much of the argument might then indicate that under certain conditions a higher plasma to cell gradient might occur with a high  $\text{CO}_2$  and low hemoglobin saturation than with a ninety-five to one hundred per cent oxygen saturation and low  $\text{CO}_2$  concentration in the blood plasma. It is a matter of great moment in this regard that at 38,000 feet in the low pressure chamber the hemoglobin saturation is not reduced when up to ten per cent carbon dioxide mixtures are substituted for one hundred per cent oxygen. Again, neither the hemoglobin oxygen saturation nor the alveolar oxygen tension is reduced very greatly at 45,000 feet by the use of ten per cent  $\text{CO}_2$ -ninety per cent oxygen mixtures instead of pure oxygen.

4. The cerebral circulation and the coronary circulation resemble each other in that capillary components differ from those elsewhere in the body in their response to vasoconstrictor agents. Schmidt (7) and others have shown that carbon dioxide is a very potent vasodilator agent in the cat and produced vasodilatation of small cerebral vessels. More recently Schmidt (8) believes that this effect is not so clearly evident for primates. However, if vasodilatation in the cerebral hemispheres does occur and systemic blood pressure and other circulatory factors remain relatively constant, it would be expected that the decrease of peripheral resistance by vasodilatation of the cerebral vessels would result in an increase of cerebral blood flow. Even if the caliber of the vascular bed in the cerebral hemispheres were to remain the same, an increased blood pressure occasioned by increased carbon dioxide might result in a steeper oxygen pressure gradient from inside the vessel to the neuron. Some evidence to support this hypothesis has been found by Brink (9).

5. The oxygen concentration of the intercellular "substrate" is probably a convenient figment of the imagination which connotes an inert homogenous substance. Between the capillaries and the neuron cell wall is a material which would be expected

to act like a series of permeable or semipermeable membranes across which oxygen and other substances diffuse. Such a conception would also predict an oxygen pressure gradient (which is not necessarily linear) from the plasma in the capillary to the cerebral neurons. Little is known of the possible effects of CO<sub>2</sub> or other substances upon the permeability or other characteristics of the substrate. The oxygen tension at any point in the substrate is a function of the distance from the capillaries, the physio-chemical status of the substrate, and the oxygen utilization rate of the neurons.

6. Nothing definitive is known about the possibility of the effect of carbon dioxide upon the utilization of oxygen by nerve cells, but this is a point which may hold considerable promise in explaining some of the phenomena described in this report.

Among other effects of carbon dioxide which are not connected directly with oxygen carriage and utilization are the stimulating effects upon respiratory centers. With the relative alkalosis occurring with the stress of combat, the propensity to hyperventilate and the alkalosis of high altitudes it would be expected that apneic periods might be expected. The direction of the reactions caused by these factors would be reversed by inhalation of carbon dioxide. There have been several reports reaching this laboratory that there are many individuals who have forgotten to breathe while concerned with the stress of missions at altitudes. This forgetting to breathe in absence of stimulation of respiratory centers (except by anoxia) has resulted in recovery from dives at lower altitudes when there has been no pilot consciousness of the dive which resulted in the lowering of the plane's altitude. The effects of carbon dioxide upon the respiratory centers in the medulla, the carotid bodies and aortic arch (10) have been studied extensively. Another effect of carbon dioxide is upon the vasomotor centers in the direction of increasing systemic blood pressure.

The evidence presented in this report consists largely of studies of brain potentials and the behavior of individuals at higher altitudes. In these experiments the subjects lay, with electrodes affixed, upon a cot in a low pressure chamber. The chamber itself was used as an electrical shield and continuous electroencephalographic recordings were made both with one hundred per cent oxygen and with ninety per cent O<sub>2</sub>-ten per cent CO<sub>2</sub> mixtures. The figure of ten per cent CO<sub>2</sub> is empirical and arbitrary and it may be that higher concentrations would be of more practical use. All of the subjects breathed pure oxygen for at least one-half hour before the ascent was made and no case of severe bends occurred in this series. The changing over of the mixtures was accomplished so that in every case the new mixture was available at the most in less than twenty seconds. In some of the experiments the switch-over was accomplished from outside the chamber without the knowledge of the subject. In many of the experiments the inside observer was instructed to switch from one gas mixture to another and his behavior observed.

The general plan of procedure was to take the denitrogenated subject to an altitude at which his electroencephalogram just began to show the electroencephalographic signs of anoxia as described in a previous report (2). When maintained at that altitude (usually 38,000 to 40,000 feet) the changes usually become more pronounced. After a variable period of time the CO<sub>2</sub>-O<sub>2</sub> mixture was substituted for pure O<sub>2</sub>. The brain wave patterns at this altitude usually returned to the control patterns with this substitution. The ascent was then continued until unusual features again appeared in the E.E.G. This altitude for most people was from 42,500 to 46,000 feet. In addition to individual and daily variations in anoxia tolerance the fit of the mask probably played a part in determining the exact levels.

Variations were made upon this procedure. At times the mixtures were switched back and forth several times at the same altitude. The rate of ascent and the times during which the subject remained at the different levels was varied. The results found indicate that with slow rates of ascent the anoxia tolerance altitude is raised. In no single instance was there any evidence that changes in the electroencephalogram were increased by the substitution of up to ten per cent CO<sub>2</sub> for some of the oxygen supply. In experiments in which the subject was carried up to altitudes of 43,000 feet and above with CO<sub>2</sub>-O<sub>2</sub> mixtures and remained there for a prolonged time, the brain wave patterns usually showed some amount of deterioration after thirty minutes to one hour. After that time the altitude tolerance slowly declined to a level at which the alveolar oxygen partial pressure was sufficient to sustain normal brain wave activity.

The last mentioned fact may have considerable importance for tactical use. If the brain wave activity bears any relation to cerebral efficiency (and it is believed that it does), then it may be that by using a ten per cent CO<sub>2</sub>-ninety per cent O<sub>2</sub> mixture the serviceable ceiling of aircrew members can be raised 3,000 to 5,000 feet for periods of time of from thirty minutes to one hour. In the case of fighter pilots this would constitute a distinct tactical advantage. Its physiological explanation may be that in spite of the reduction of alveolar oxygen tension caused by the displacement of some oxygen by carbon dioxide in the inspired gas mixture, the adjuvant effects of carbon dioxide can more than compensate for the reduction until the steady state is reached. From these data it would appear that the time required for steady state conditions to become operative would be of an order of magnitude approximating thirty minutes to one hour.

The general clinical appearance and efficiency of behavior of each subject studied in this series was either the same or better at altitudes above 38,000 feet when breathing a carbon dioxide mixture as compared to his status when breathing pure oxygen. As mentioned in a previous report (1), the clinical appearance and efficiency of behavior is often markedly bettered by the substitution of carbon dioxide for ten per cent of the oxygen.

TABLE 1  
HEMOGLOBIN SATURATION WITH OXYGEN

<u>Subject</u>	<u>Altitude</u>	<u>With 100% O<sub>2</sub></u>	<u>With 10% CO<sub>2</sub>, 90% O<sub>2</sub></u>
V.I.	46,000 feet	78%	76%
J.M.B.	46,000 feet	68%	65%
P.K.S.	44,000 feet	74%	71%
D.L.C.	38,000 feet	92%	90%
M.A.P.	38,000 feet	87%	88%
C.R.Jr.	38,000 feet	88%	86%
C.L.F.	38,000 feet	95%	94%
R.L.C.	38,000 feet	86%	86%
P.L.C.	38,000 feet	92%	93%
? R.	35,000 feet	94%	94%
J.R.	35,000 feet	93%	93%
J.R.S.	35,000 feet	92%	92%
M.W.T.	35,000 feet	92%	92%
Holland	35,000 feet	96%	96%
Hackbarth	35,000 feet	93%	93%

The O<sub>2</sub> saturation readings were taken with the Millikan oximeter.



MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT

to

ARMY AIR FORCES MATERIEL COMMAND  
Under Contract No. W535-ac-25829

Subject: Comments on "A Study of Hyperventilation as a Means of Gaining Altitude" by L. E. Chadwick, A. B. Otis, H. Rahn, M. A. Epstein and W. O. Fenn, (C.A.M. Report No. 302, May 22, 1944) made at the request of Chief, Aero Medical Laboratory, Engineering Division, Wright Field.

Serial Report: Series A, No. 8

Date: July 4, 1944

1. Summary:

1 a. The experimental part of the paper under review provides convincing explanations for the efficacy of voluntary pressure breathing and intermittent pressure breathing. At 18,000 feet, when air is being breathed, the value is due mainly to increased ventilation; at 42,000 feet, with oxygen, the increased pressure is beneficial in itself.

1 b. The theoretical part, although open to criticism in certain particulars, provides an excellent analysis, in terms suggested by the familiar alveolar air equation supplemented by calculations of ventilation rates, of the hyperventilation of anoxia and the effects of inhaling carbon dioxide.

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2. The paper under review makes a twofold contribution to the study of tolerance to high altitude. Part I is devoted to quantitative consideration of the mechanisms available to the body in responding to conditions involving a certain degree of anoxia. Part II is an experimental study of claims made by Commoner and others as to the value of a valsalva maneuver in combating the effects of anoxia ("voluntary pressure breathing," VPB).

3. Voluntary pressure breathing:

3 a. The surprising thing about VPB, according to the earlier studies, is that it is equally beneficial in lowering the effective altitude, whether this subject is breathing air or oxygen. This is surprising because a given increase of intrapulmonary pressure should be only about one-fifth as effective for air as for oxygen, unless some other mechanism, in addition to mere compression of pulmonary gas, is involved. Hyperventilation at once suggests itself, and Fenn's experiments were directed toward a rather detailed comparison of the effects of VPB and voluntary hyperventilation at simulated altitudes of 18,000 and 42,000 feet. The investigators measured ventilation rate, alveolar gas composition, intrapulmonary pressure, oxygen consumption and arterial percentage saturation (oximeter).

3b. The results were in general what would have been expected. The findings of Commoner and Gemmill were confirmed, and further light was shed upon the different relative importance of the two mechanisms involved - true "pressure breathing" and "hyperventilation" - at 18,000 feet and 42,000 feet. At the lower altitudes breathing air, the improvement is due chiefly to hyperventilation; at 42,000 feet the pressure, as such, is five times as effective as at 18,000 feet, so that at 42,000 feet quite a significant improvement can be obtained without the fall in

alveolar CO<sub>2</sub> consequent upon hyperventilation, with its accompanying risk of acapnia. At both altitudes, however, the tendency to increase the ventilation rate while performing the maneuver is quite pronounced. It should also be stressed that the subject is readily fatigued and that the oxygen consumption increases by about 43 per cent as a result of the muscular effort involved. This stands in contrast to the absence of any conspicuous increase during ordinary PB (C.A.M. No. 111). The effort needed, moreover, is greater at 42,000 feet than at 18,000 feet because of the greater volume change associated with a given increase in intrapulmonary pressure at the higher altitudes.

3 c. Altogether I see no good reason for objecting to the authors' conclusion that "VPB should be a useful emergency measure for temporary alleviation of anoxic symptoms at altitudes of 40,000 feet or higher where oxygen is breathed . . . . At altitudes where air is breathed, voluntary hyperventilation without pressure is more economical than VPB and equally effective." The same remarks apply with equal force to intermittent pressure breathing with the aid of a regulating device, and thus provide a natural explanation for the effectiveness of intermittent pressure breathing of air (Behnke, White, Consolazio and Pace, C.A.M. 189).

#### 4. Theory of hyperventilation as a means of gaining altitude:

4 a. The importance of this section, in my opinion, is in the stress laid upon the need for a more complete picture than that provided by an "alveolar air equation" alone. The factor most conspicuously neglected is the ventilation rate, and Fenn has taken an important step in combining a consideration of ventilation rates with the alveolar air equation. It is obvious enough that we have no right to define the physiological states of a subject as "identical" under two different sets of conditions merely because his alveolar oxygen and carbon dioxide pressures happen to be the same in the two instances. It is necessary to know something of the mechanism involved, and this information is not provided by the simple alveolar air equation. To give a simple and extreme illustration, it is perfectly easy, according to the alveolar air equation, to increase the alveolar oxygen pressure by adding CO<sub>2</sub> to the inspired air. There is nothing in the equation to prevent our adding 34 mm. CO<sub>2</sub>, keeping the alveolar CO<sub>2</sub> constant at 35 mm., and thus preventing any significant dilution of tracheal O<sub>2</sub> by CO<sub>2</sub> added in the lungs. In practice this is obviously impossible because of the enormous increase in ventilation rate that would be required in order to blow off CO<sub>2</sub> at the normal rate without allowing the alveolar CO<sub>2</sub> pressure to rise above 35 mm.

4 b. Such considerations represent an important attempt to express in quantitative terms the conflicting effects of hyperventilation recognized long ago (cf. Boothby, Lovelace and Benson, J. Aeronautical Sci., 7, 461, 1940) - the initial gain in altitude succeeded sooner or later by acapnia. The authors also draw attention to the fact that the value of hyperventilation, in its early stages, is a twofold one:

- (a) the "mechanical" effect of diluting the alveolar CO<sub>2</sub> and thus raising the alveolar oxygen pressure,
- (b) the accompanying increased rate of CO<sub>2</sub> elimination, at the expense of CO<sub>2</sub> stored in the body, which by raising the momentary value of Q, the alveolar respiratory quotient, causes a further increase in alveolar oxygen pressure at the expense of nitrogen when air is being breathed.

Effect (b) occurs only when nitrogen is present in the inspired air, and is implicit in the choice of a suitable value of  $Q$  when the alveolar air equation is used in the calculation of equivalent altitudes. This fact seems to escape the authors when, on p. 3 ff, they say that "45,000 feet on pure oxygen is far worse than 18,500 feet breathing air, although the calculated alveolar oxygen should be the same if  $Q = 1$ ," attributing the disagreement to factor (b). According to Curve 3, in Fig. 1 of our C.A.M. Report No. 222, however, 45,000 feet breathing oxygen is equivalent to 20,000 feet breathing air, provided that the degree of hyperventilation at 20,000 feet is the same as that implied in Boothby's data by the observed values of the alveolar oxygen and carbon dioxide and an alveolar respiratory quotient of about 1.0.

4 c. I am<sup>also</sup> unable to follow them when, largely on the basis of this supposed disagreement, they argue that equivalent altitudes should be defined as "those in which the sums of the  $pCO_2$  and  $pO_2$  in the alveolar air are equal." It is readily shown from the alveolar air equation that this new criterion gives exactly the same equivalent altitudes as those obtained when equality of  $pO_2$  and  $pCO_2$  values, taken separately, is the criterion. In both cases, moreover, we have to specify a particular degree of hyperventilation before our equivalents are valid; with any other degree of hyperventilation we should arrive at a different series of equivalents. Brink, in the "Handbook of Respiratory Data," assumes no hyperventilation and an entirely fictitious steady state; we, in Report No. 222, assumed the  $Q$  value for a non-steady state implied in Boothby's average data.

4 d. It should be added that much existing information on the physiology of high altitude flight is presented in this paper in the form of diagrams of a novel kind which deserve serious consideration. In these, the alveolar  $CO_2$  is plotted against alveolar oxygen and the diagram is traversed by any desired number of lines for equal altitude, equal  $RQ$ , equal per cent saturation, equal ventilation rates and so forth.

4 e. We have been studying this paper very closely in conjunction with Fenn's previous reports, C.A.M. 111 and 249, and hope to make more detailed comments in the near future. The present remarks represent a rather hurried judgement which may have to be revised in some particulars.

Prepared by J. B. Bateman  
Mayo Aero Medical Unit



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MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT

to

ARMY AIR FORCES MATERIEL CENTER  
Under Contract No. W535ac-25829

SUBJECT: Effect on ceiling attainable and on the alveolar air data of 3 individuals originally acclimatized to low levels (1,000 feet, Rochester, Minnesota) by going to the higher levels around Colorado Springs (6,200 feet).

SEPIAI REPORT: Series A, Report No. 8a  
By Walter M. Boothby and Capt. J. W. Wilson

August, 1944

A. Purpose

The Mayo Aero Medical Unit in cooperation with the Aero Medical Laboratory of Wright Field carried out a joint investigation to determine whether or not preliminary acclimatization to high altitude (6,200 feet) would increase the ability of an aviator to ascend to a higher ceiling.

This report is limited to reporting the increase in the ceiling and changes in the alveolar air data obtained on 3 individuals in the low pressure chamber, first at Rochester, Minnesota with the subjects living at an altitude of 1,000 feet and second, in the low pressure chamber at Peterson Field, Colorado Springs, where the subjects gradually became acclimatized to living at an altitude of approximately 6,200 feet.

B. Summary

(a) Living for two weeks at an altitude of 6,200 feet definitely and significantly increased the altitude a subject could attain in a low pressure chamber over that which he attained when living at 1,000 feet.

(b) No significant increase in ceiling was attained within the first three days of living at 6,200 feet.

(c) The change in level and acclimatization ~~therefore~~ did not consistently alter the alveolar air data obtained on ascending in a low pressure chamber in the case of the three subjects studied.

Subject: Henrietta Cranston  
Age 37 years; weight 49.7 kg.; height 157 cm. and S.A. 1.38 sq. m.

Arrived at 6,200 level, Peterson Field, Colorado Springs (July 20, 1944)

1,000 foot level, Rochester, Minnesota

Elevation	Barometer	CO <sub>2</sub> %	Alveolar Air Data			ARQ
			mm.	O <sub>2</sub> %	mm.	
<u>Ground</u>						
1,000 ft.	739	4.87	34	14.59	101	0.72
3,000 ft.	679	4.90	31	14.86	94	0.76
6,000 ft.	606	5.58	31	13.94	79	0.75
9,000 ft.	544	6.28	31	13.13	65	0.76
10,000 ft.	523	6.90	33	13.48	64	0.90
12,000 ft.	483	6.91	30	12.69	55	0.80
13,000 ft.	459	8.06	33	11.06	46	0.77
15,000 ft.	429	7.99	31	12.18	46	0.89
17,000 ft.	396	8.19	29	11.24	39	0.81
18,000 ft.	379	9.33	31	12.30	41	1.10
19,000 ft.	368	8.38	27	11.25	36	0.83
20,000 ft.	349	10.10	31	12.92	39	1.35

6,200 ft. level, Peterson Field, Colorado Springs  
July 22, 1944 (2 days after arrival)

Ground						
6,200 ft.	609	4.90	28	15.00	84	0.78
9,000 ft.	539	5.71	28	14.35	71	0.83
12,000 ft.	479	5.90	26	13.58	59	0.76
15,000 ft.	432	6.57	25	12.71	49	0.75
18,000 ft.	382	6.98	23	12.70	43	0.81
20,000 ft.	347	6.81	21	12.68	38	0.78

6,200 ft. level, Peterson Field, Colorado Springs  
August 4, 1944 (15 days after arrival)

Ground						
6,200 ft.	611	4.73	27	15.51	88	0.84
9,000 ft.	541	5.25	26	14.81	73	0.82
12,000 ft.	483	5.85	26	14.03	61	0.81
15,000 ft.	432	6.56	25	13.04	50	0.79
18,000 ft.	382	6.85	23	12.65	42	0.79
20,000 ft.	352	7.22	22	12.33	38	0.80
22,000 ft.	323	7.21	20	12.50	35	0.82
24,000 ft.	296	7.37	18	12.33	31	0.82
26,000 ft.	272	7.38	17	12.34	28	0.82

Subject: Rita Schmelzer  
Age 39 years; weight 65 kg.; height 158 cm. and S.A. 1.67 sq. m.

Arrived at 6,200 ft. level, Peterson Field, Colorado Springs (July 20, 1944)

1,000 ft. level, Rochester, Minnesota

Elevation	Barometer	Alveolar Air Data				
		CO <sub>2</sub> %	mm.	O <sub>2</sub> %	mm.	ARQ
<u>Ground</u>						
1,000 ft.	741	4.64	32	15.62	108	0.84
10,000 ft.	523	6.30	30	13.32	64	0.79
13,000 ft.	469	7.81	33	12.13	51	0.86
15,000 ft.	426	7.77	30	12.16	46	0.85
17,000 ft.	395	8.46	30	11.38	40	0.86
18,000 ft.	379	8.46	28	11.35	38	0.85
20,000 ft.	349	8.86	27	11.98	36	0.98

6,200 ft. level, Peterson Field, Colorado Springs  
July 24, 1944 (4 days after arrival)

6,000 ft.	609	5.41	30	14.25	80	0.77
9,000 ft.	546	6.04	30	12.76	64	0.69
12,000 ft.	485	6.41	28	12.39	54	0.70
15,000 ft.	431	7.25	28	11.21	43	0.69
18,000 ft.	382	7.53	25	10.81	36	0.69
20,000 ft.	353	7.87	24	10.44	32	0.70

6,200 ft. level, Peterson Field, Colorado Springs  
August 5, 1944 (16 days after arrival)

6,000 ft.	613	5.88	33	13.87	79	0.79
9,000 ft.	540	6.64	33	12.72	63	0.76
12,000 ft.	480	7.04	31	12.86	56	0.84
15,000 ft.	427	7.75	29	11.37	43	0.77
18,000 ft.	380	7.83	26	11.59	39	0.80
20,000 ft.	346	8.28	25	10.26	31	0.73
22,000 ft.	321	8.07	22	10.40	29	0.72
24,000 ft.	294	8.61	21	10.48	26	0.78

Subject: Capt. J. W. Wilson (Wright Field)  
Age 27 years; weight 79 kg.; height 1.82 cm., and S.A. 2.02 sq. m.

Arrived at 6,200 ft. level, Peterson Field, Colorado Springs (July 20, 1944)

1,000 ft. level, Rochester, Minnesota

Elevation	Barometer	Alveolar Air Data				
		CO <sub>2</sub> %	mm.	O <sub>2</sub> %	mm.	ARQ
Ground						
1,000 ft.	728	5.40	37	14.85	101	0.86
6,000 ft.	608	6.64	37	13.07	73	0.81
10,000 ft.	522	7.63	36	12.03	57	0.82
15,000 ft.	430	8.93	34	10.53	40	0.82
18,000 ft.	380	9.11	30	10.62	35	0.85

6,200 ft. level, Peterson Field, Colorado Springs  
July 22, 1944 (2 days after arrival at Peterson Field)

Ground						
6,200 ft.	609	6.17	35	13.90	78	0.84
9,000 ft.	539	7.11	35	12.67	62	0.82
12,000 ft.	479	7.97	35	11.45	49	0.80
15,000 ft.	432	8.40	32	11.10	43	0.82
18,000 ft.	382	8.80	30	10.61	36	0.82
20,000 ft.	347	8.59	26	11.15	34	0.85
22,000 ft.	321	8.44	23	11.59	32	0.88

6,200 ft. level, Peterson Field, Colorado Springs  
August 4, 1944 (15 days after arrival at Peterson Field)

Ground						
6,200 ft.	611	6.43	36	13.32	75	0.81
9,000 ft.	541	7.49	37	11.88	59	0.79
12,000 ft.	483	8.42	37	11.05	48	0.82
15,000 ft.	432	9.01	35	10.48	40	0.83
18,000 ft.	382	9.41	32	10.41	35	0.87
20,000 ft.	352	9.24	28	10.65	33	0.87
22,000 ft.	323	9.63	27	10.16	28	0.87
24,000 ft.	296	9.19	23	11.01	27	0.90
26,000 ft.	272	8.71	20	11.28	25	0.87



MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT

to

AIR TECHNICAL SERVICE COMMAND  
Under Contract No. AC-25829

SUBJECT: Effect of ascent in a low pressure chamber on the alveolar air composition of individuals acclimatized to an altitude of approximately 6200 feet. An elaboration of the report made by Capt. J. W. Wilson of Wright Field on a joint study by the Army Air Forces and the Mayo Aero Medical Unit.

SERIAL REPORT: Series A, No. 8b  
Prepared by W. M. Boothby, Mayo Aero Medical Unit.

DATE: September 1944

A. Purpose

The Mayo Aero Medical Unit in cooperation with the Aero Medical Laboratory of Wright Field carried out a joint investigation to determine whether or not preliminary acclimatization to the high altitude of Peterson Field, Colorado Springs, Colorado, (approximately 6200 feet) would significantly alter the composition of the alveolar air in such a manner that the ceiling of an aviator would be materially increased.

In our Report Series A, 8a we have presented the alveolar air data obtained upon ascent in a low pressure chamber on three individuals fully acclimatized to the ground elevation at Rochester, Minnesota, of 1000 feet and upon ascent within two days and again at the end of two weeks after arriving at Colorado Springs. Little change in the  $pCO_2$  and  $pO_2$  was found within two weeks as a result of change of the ground level; in one of three subjects studied greater variation in the alveolar respiratory quotient was obtained at Rochester than at Colorado Springs. The greater distortion in the alveolar respiratory quotient at 1000 feet was probably due not only to the effect of hyperventilation on the alveolar oxygen and carbon dioxide pressures but also to the effect of rapid changes in elevation on the alveolar nitrogen pressure. Also in rapid ascent in the low pressure chamber more time is required to reach a "steady state" in regard to both factors when the start of ascent is from 1000 feet or less where the alveolar partial pressure of nitrogen is around 540 mm. than when the ascent is made from around 6000 feet where the nitrogen pressure is reduced to around 445 mm.; in the former case an ascent of 19,000 feet causes a change in  $N_2$  pressure of 300 mm. and in the latter only 245 mm.

B. Summary

Attached is the report prepared by Captain Wilson from 542 observations on 32 subjects by a modified Haldane-Priestley method of obtaining an alveolar air sample; the sample was obtained on completion of a forceful rapid expiration starting from the top of inspiration. All Peterson Field personnel were untrained in giving alveolar airs; therefore, a few preliminary determinations were made at ground level. All determinations are included in the ground averages and in the accompanying chart. Two samples collected over mercury were taken at each elevation: the first 10 minutes after reaching elevation and the second 5 minutes later. The alveolar air samples were analyzed by trained technicians of the Mayo Aero Medical Unit on calibrated Haldane gas analyzers.

All but three subjects (Mayo technicians) were Air Force personnel who had been living at Peterson Field, Colorado, at an altitude of 6200 feet for over two months; in fact, all but two had been there more than six months and, therefore, were fully acclimatized. From the data presented on the accompanying chart it is seen that, on the average, individuals so acclimatized will on short rapid ascents to higher altitudes in a low pressure chamber have an alveolar  $\text{CO}_2$  pressure 4 mm. lower and an  $\text{O}_2$  pressure 6 mm. higher than the average individuals living at an altitude of 1000 feet.

Two charts are also attached which show the influence on subjects acclimatized to an elevation of 1000 feet which the role of changing oxygen and nitrogen pressures can play in rapid ascent to 15,000 feet in the calculation of the "alveolar pressure ratio." Time must be allowed for both  $\text{O}_2$  and  $\text{N}_2$  pressures to reach equilibrium; on ascent to higher altitudes there will be the added effect of the washing out of  $\text{CO}_2$  caused by the anoxic drive.

The term "respiratory quotient" is synonymous with combustion quotient and should always be so used. The amount of  $\text{CO}_2$  formed in relation to the  $\text{O}_2$  burned varies with the proportion of fat or carbohydrate serving the body as fuel at the time. To obtain an accurate R.Q. it is necessary to correct for the change in volume of the expired air from the inspired air produced by the character of the food consumed. As nitrogen is an inert gas and is constant in outdoor atmospheric air this change in volume can be calculated by utilizing the ratio of nitrogen in the expired or alveolar air to the nitrogen in the inspired air provided the subject is in a steady state, breathing normally without hyperventilation, and provided the inspired air is pure air, otherwise it must be analyzed and the data used in the calculation. If hyperventilation is present from any cause, especially in aviation as a result of the "anoxic drive" produced by ascending to high altitude, there is a washing out of  $\text{CO}_2$ . The effect of the washing out of  $\text{CO}_2$  is well recognized; the effect from the simultaneous but more transient changes in the nitrogen and oxygen pressures are less generally considered in their rôle as variables in the early stages of compensation especially when the change in nitrogen from inspired to expired air is used in the calculation in an attempt to obtain a valid respiratory quotient. The latter can only be obtained if the subject is in a steady state and also if the elevation is maintained constant for a considerable period.

APMY AIR FORCES  
HEADQUARTERS, AIR SERVICE TECHNICAL COMMAND  
ENGINEERING DIVISION  
MEMORANDUM REPORT ON

Capt. J.W.Wilson

SUBJECT: Alveolar Air Composition

Date: 16 September 1944

SECTION: Aero Medical Laboratory

SERIAL No. ENG-49-696-42-F

A. Purpose:

1. To study the effect of acclimatization of individuals to 6200 feet altitude upon the alveolar air composition.

B. Factual Data:

1. Experiments were carried out at Peterson Field, Colorado to determine the effect of acclimatization of individuals to an altitude of 6200 feet upon the composition of alveolar air. A total of 32 subjects was used. (See Table I for ages and periods of acclimatization.)

2. The procedure in these tests was to collect samples of alveolar air at ground level and at a number of simulated altitudes between 9000 feet and the highest altitude which the individual could tolerate while breathing atmospheric air. The subject remained at each altitude for a total of 15 minutes, or slightly longer, during which time two samples of alveolar air were taken.

3. Following this procedure two-thirds of the individuals were able to tolerate altitudes up to at least 24,000 feet, and one was able to go as high as 28,000 feet (Table I).

4. Comparison of the composition of alveolar air obtained on this group with that obtained at the Mayo Aero Medical Unit, Rochester, Minnesota on individuals acclimatized to approximately 1000 feet altitude shows significant differences between the two. The partial pressures of carbon dioxide of alveolar air were lower in the Peterson Field Group than in the Rochester Group, and the pressures of oxygen were as a first approximation correspondingly higher. (Figure 1).

5. Incidental to the alveolar air studies, observations were made on the subjective and objective symptoms of the subjects during and after the altitude flights. The outstanding objective symptoms (signs) during the period of anoxia were bloodshot eyes and paling of the face. The most commonly reported subjective symptoms during this period, in the order of frequency of being experienced, were light-headedness (vertigo), headache, sensation of improvement shortly after levelling off at a given altitude, blurring (dimming) of vision, sleepiness, nausea, and tingling of extremities. (See Table II for more complete analysis of symptoms.)

6. Periods of anoxia of an intensity and duration similar to those in these experiments are commonly believed to be followed by rather severe headaches and other debilitating symptoms, but it is worthy of note that the post-experiment reactions were on the contrary rather mild in character with a few exceptions (Table I).

C. Conclusions:

1. Acclimatization of individuals, who have been living at or near sea level, to approximately 6000 feet produces a significant change in alveolar air composition. Also such acclimatization increases the individual's altitude-tolerance ceiling.
2. Of the symptoms encountered in these experiments the only ones experienced by the large majority of individuals were light-headedness (vertigo) and blood-shot eyes.
3. Periods of anoxia of the duration and intensity of those in these experiments are not necessarily followed by severe headaches or other markedly debilitating symptoms.

D. Recommendations:

1. None.

Assisted by Pvt. Walter K. Gibbs and technicians from the Mayo Clinic.

Prepared by FRANK G. HALL, Lt. Col., A.C.  
Chief, Physiological Branch

Prepared by JOHN W. WILSON, Capt. S.A.C.

Approved by FRANK G. HALL, Lt. Col., A.C.  
Acting Chief Aero Medical Laboratory

Approved by F. O. Carroll, Brig. Gen., USA  
Chief, Engineering Division

TABLE I

A table showing: The age and period of acclimatization of the subjects; the maximal altitude attained by each; and the subjective symptoms of the individuals after the period of anoxia. The subjects in this experiment breathed atmospheric air of simulated altitudes between 12,000 feet and the maximal altitude which the individual could tolerate. The plus (+) or minus (-) sign indicates the presence or absence, respectively, of the particular symptom.

Subject	Age (Yrs.)	Acclimatization Period (Months)	Maximal Altitude Attained (in feet)	Headache after Descent Percent	Lightheaded (vertigo) after Descent	
1	22	6	22,000	+ (mild; 3 or 4 hours)	-	
2	20	15	24,000	+ (mild; about 3 hours)	--	
3	24	22	24,000	+ (mild; about 20 min.)	- (slight muscular weakness)	
4	30	12	20,000	+ (mild)	-	
5	23	22	24,000	+ (mild; 10 or 15 min.)	-	
6	27	20	24,000	+ (mild)	-	
7	25	6	24,000	+ (mild; 1 hour)	-	
8	19	6	27,000	+ (pretty bad"; 1 hr.)	--	
9	26	6	22,000	-	+ (slight)	
10	22	15	24,000	+ (very intense at first)	-	
11	23	22	24,000	+ (intense at first)	-	
12	27	22	22,000	-	-	
13	28	22	22,000	-	-	
14	21	6	20,000	+ (intense; mild after 1/2 hour)	-	
15	20	6	24,000	+ (mild; 2 hours)	+ (10 to 15 minutes)	
16	21	6	22,000	-	+	
17	21	1/2	18,000	+ (medium; remainder of day)	-	
18	(?)	1/2	24,000	+ (mild; 5 hours)	+ (5 to 10 minutes)	
19	37	1/2	26,000	-	-	
20	31	1/2	26,000	+ (very mild; 10 min.)	- (slight muscular weakness)	
21	21	3	28,000	+ (mild)	-	

TABLE I (cont.)

<u>Subject</u>	<u>Age (Yrs.)</u>	<u>Acclimatization Period (Months)</u>	<u>Maximal Altitude Attained (in feet)</u>	<u>Headache after Descent</u>	<u>Lightheaded (vertigo) after Descent</u>
22	21	17	24,000	-	-
23	20	2	24,000	-	+ (15 or 20 minutes)
24	21	8	27,000	-	-
25	33	10	24,000	-	-
26	29	15	20,000	-	-
27	28	8	24,000	-	-
28	31	16	22,000	+ (mild)	-
29	29	1-1/2	20,000	-	-
30	20	7	26,000	- (nausea)	-
31	30	8	24,000	+ (intense)	-
32	27	15	24,000	+ (intense)	-

TABLE II.

A table of the subjective and objective symptoms experienced by subjects while breathing atmospheric air at simulated altitudes between 12,000 feet and the highest altitude which the individual could tolerate.

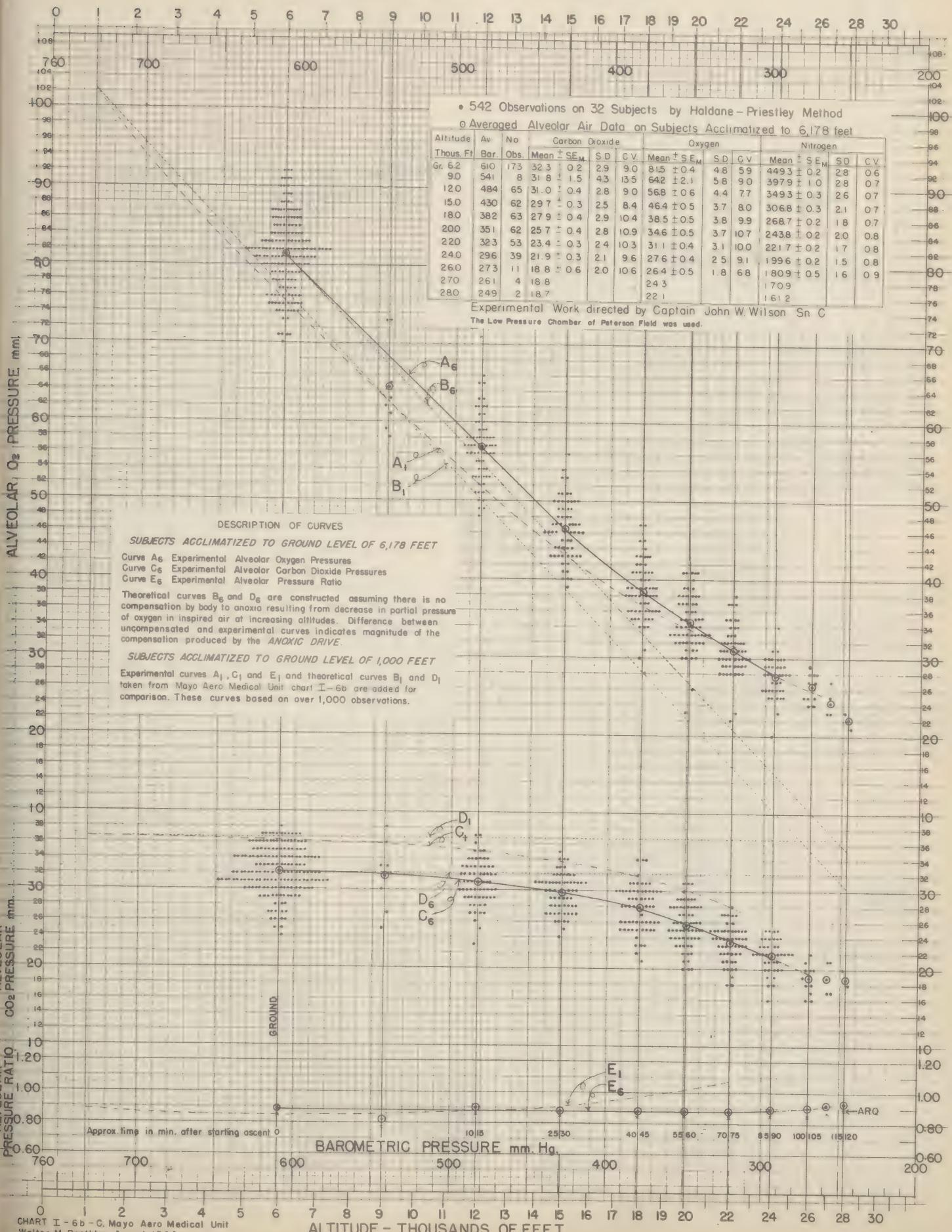
<u>Subjective Symptoms</u>	<u>Number of Subjects Experiencing Symptoms</u>	<u>Objective Symptoms</u>	<u>Number of Subjects Experiencing Symptoms</u>
Light-headedness (vertigo)	22	Bloodshot eyes	Most subjects (not counted)
Headache	14	Paling	14
Improvement shortly after one or more ascents	9	Muscle tremors and poor muscular control.	Several subjects (not counted)
Blurring (dimming) of vision	9	Marked hyperventilation.	4
Sleepiness	9	Periodic sighing	2
Tingling of extremities	9		
Nausea	7		
Muscular weakness	4		
Chilliness	4		
Felt inebriated	3		
Pressure around eyes	2		
Restlessness	1		
Slow visual accommodation	1		

ALVEOLAR O<sub>2</sub> AND CO<sub>2</sub> PRESSURES AND ALVEOLAR RATIOS AT VARIOUS ALTITUDES WHILE BREATHING AIR

A Cooperative Study carried out at Peterson Field, Colorado Springs, Colorado by

WRIGHT FIELD AERO MEDICAL LABORATORY AND MAYO AERO MEDICAL UNIT

SUBJECTS ACCLIMATIZED TO 6,180 FEET



Mayo Aero Medical Unit

**ALVEOLAR O<sub>2</sub> AND CO<sub>2</sub> PRESSURES AND ALVEOLAR R.Q. BREATHING AIR**

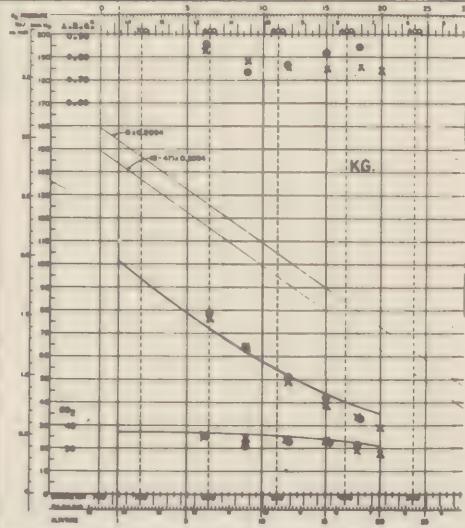
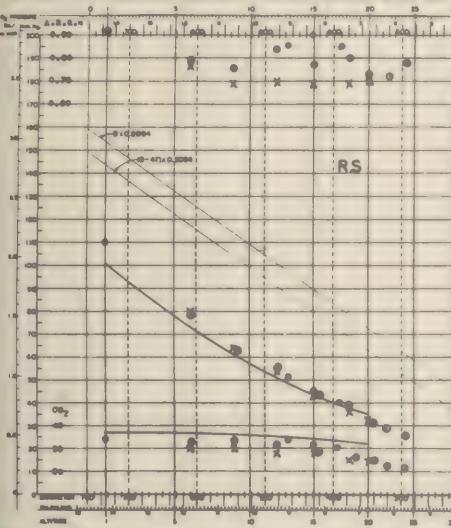
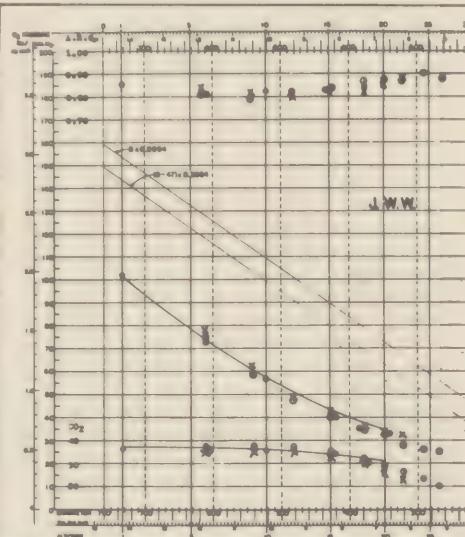
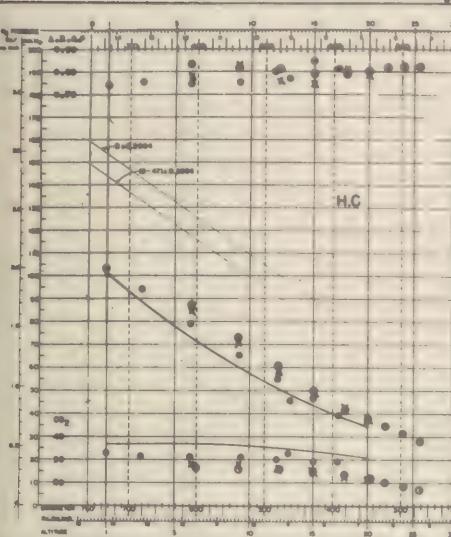
Data obtained at Colorado Springs (6,180 feet)

X Shortly after arrival (1 flight)

○ After two weeks (1 flight)

Data obtained previously at Rochester, Minnesota (1,000 feet)

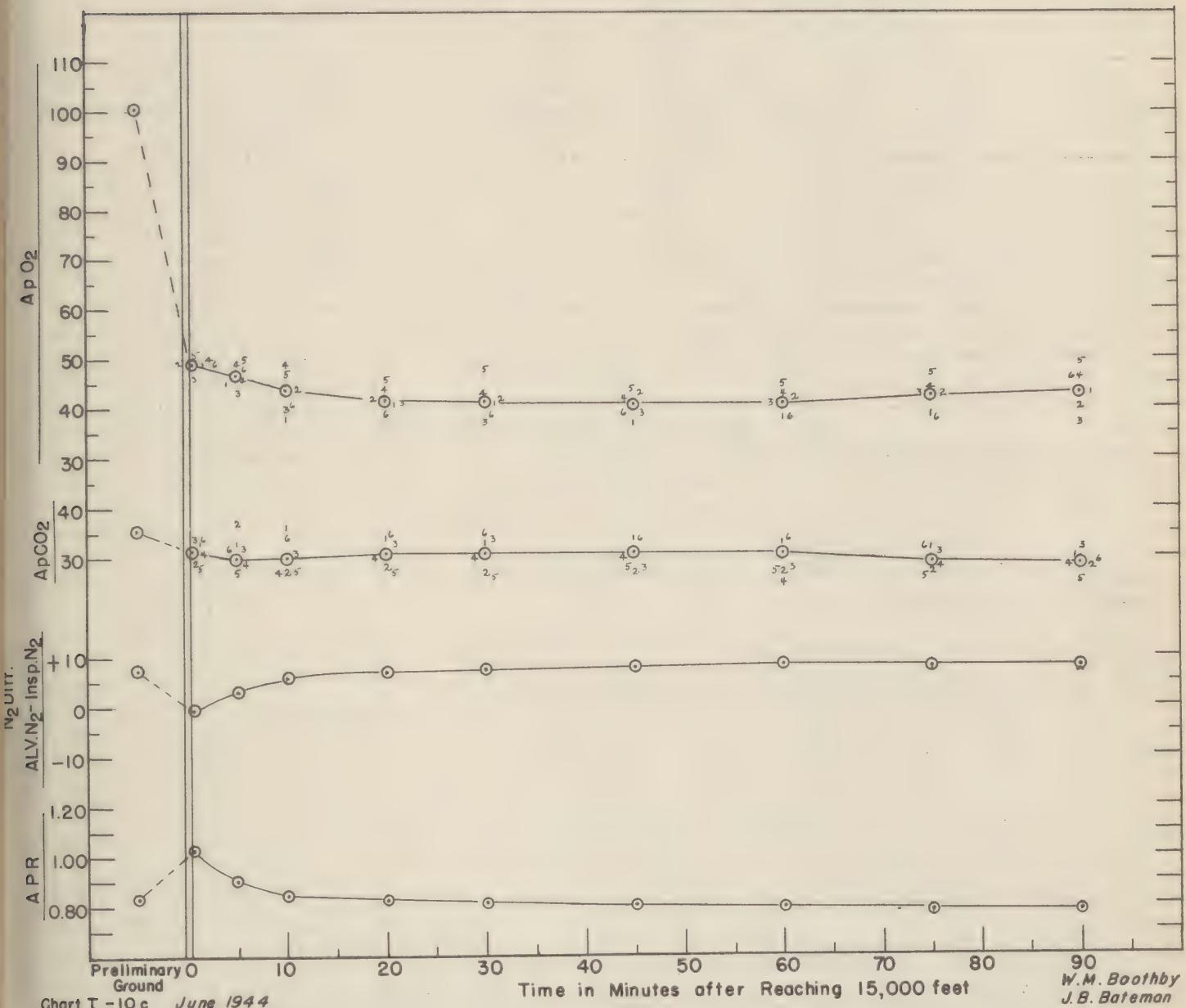
● Average of several flights



W. M. Boothby  
Sept. 1944  
Chart I-6b-1

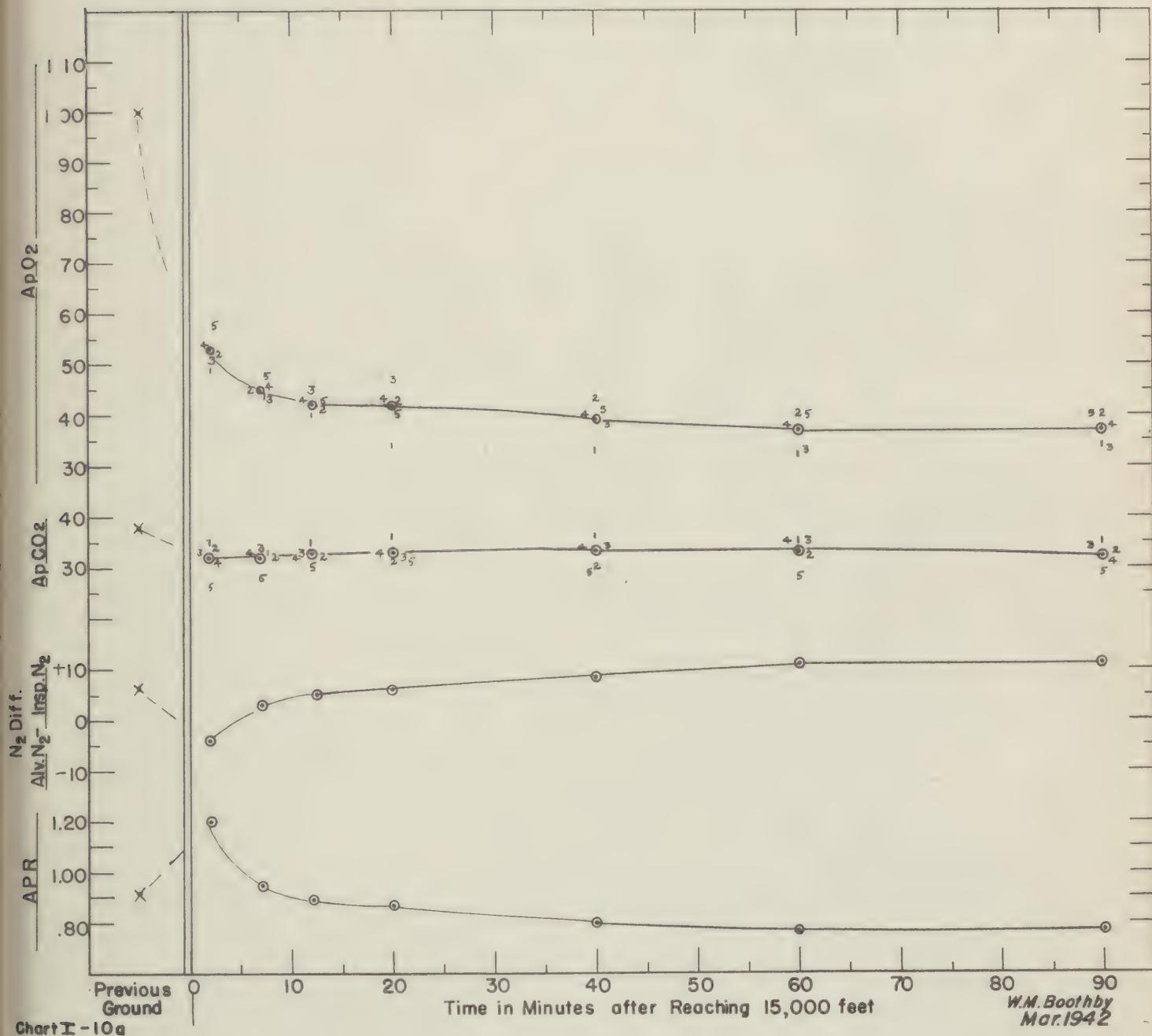
*Mayo Aero Medical Unit*  
**Alveolar O<sub>2</sub> and CO<sub>2</sub> Pressures and Alveolar Pressure Ratios  
 as affected by Duration of Stay at 15,000 feet**

*Six subjects went to 15,000 feet without Oxygen. Alveolar airs were obtained at intervals up to 90 minutes*



MAYO AERO MEDICAL UNIT  
 Alveolar O<sub>2</sub> and CO<sub>2</sub> Pressures and Alveolar Pressure Ratios  
 as affected by Duration of Stay at 15,000 feet

Five subjects were taken to 15,000 feet on "normal" oxygen, about 10 minutes at altitude mask was removed and alveolar airs obtained at intervals up to 90 minutes



W.M. Boothby  
Mar. 1942

Chart II - 10a



MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT

to

AIR TECHNICAL SERVICE COMMAND  
Under Contract No. W535-ac25829

Subject: Comments on "The Calculation of Equivalent Altitudes, by J. S. Gray," \* prepared at the request of Chief, Aero Medical Laboratory, Engineering Division, Wright Field.

Serial Report: Series A, No. 9

Date: October 18, 1944

(1) The paper "The Calculation of Equivalent Altitudes" (Gray, 1944 b) contributes a useful compilation of experimental data on the alveolar oxygen pressures or arterial oxygen saturations of men breathing various gas mixtures at various decompression chamber pressures. Expressed in terms of the altitudes at which men breathing air would have, on the average, the same alveolar oxygen pressures or the same arterial saturations, these data thus provide tables of "equivalent altitudes." Equivalent altitudes can also be calculated, and it is useful to have these tables of "experimental equivalent altitudes" with which to justify the calculations. This is of particular value because there happen to be at least three methods of making the calculation, and the three methods do not all give the same answer.

(2) To place this contribution in perspective let us once more enumerate the common methods for calculating equivalent altitudes and the information that is needed in order to carry out the calculations.

(i) Equality of oxygen partial pressures in dry inspired gas. For this we need to know only the variation of barometric pressure with altitude and the fraction of oxygen in dry air in order to establish a reference table.

(ii) Equality of oxygen partial pressures in inspired gas saturated with water vapor at body temperature (tracheal air). For this we must also know the vapor pressure of water at 37° C.

(iii) Equality of oxygen partial pressures in alveolar gas. The average composition of alveolar air depends upon (I) the composition and pressure of the inhaled gas, and upon (II) the various complex factors controlling gas exchange in the lung. The latter can usually be characterized to a first approximation by three mutually dependent variables in addition to composition and pressure of inhaled gas: the respiratory quotient,\*\* and the alveolar partial pressures of carbon dioxide and oxygen. These are not primary physical data; they have to be determined experimentally. Our reference table must therefore contain experimental values of these quantities for men breathing air at various altitudes. The actual experimental data are usually alveolar oxygen and alveolar carbon dioxide and therefore alveolar nitrogen; the calculation of the respiratory quotient from these is a matter of applying an equation which within the framework of certain plausible assumptions (these are stated and examined by Bateman and Boothby, 1944) must be correct. Once the reference table is established, the same equation can

\* A.A.F., School of Aviation Medicine, Randolph Field, Project No. 291, Report No. 1, 19 July 1944.

\*\*which may or may not be the same as the metabolic respiratory quotient or combustion quotient.

be applied in calculating the alveolar oxygen pressure of a man breathing any gas mixture of known composition at any known altitude provided appropriate values of the respiratory quotient and the alveolar carbon dioxide pressure can be assumed. Then the altitude at which the same alveolar oxygen is found in the reference table can be taken as the equivalent altitude. We see at once that by this method of calculation, the result depends upon the choice of proper values for the respiratory quotient and the alveolar carbon dioxide pressure. In other words, using the alveolar air formulation, it is not actually possible to calculate equivalent altitudes solely on the basis of alveolar or arterial oxygen pressures. The respiratory quotient and carbon dioxide pressures have to be specified as well. The simplest assumption is that they are the same as those given in the reference table at the equivalent altitude.

Even if we define equivalence on the alveolar air standard as implying equal alveolar oxygen and carbon dioxide pressures and equal respiratory quotient, we are still faced with a choice, especially in the case of conditions involving some anoxia. During the establishment of such conditions the alveolar gases are undergoing rapid change of composition, and the subject is in a non-steady state in which no use can be made of alveolar gas analyses; when external conditions become constant, the subject stabilizes in a "semisteady state"<sup>\*</sup> of high respiratory quotient, which in the course of an hour or so may, if conditions are not too severe, settle down to a new steady state in which the normal value of the respiratory quotient is restored. Thus two different calculations of equivalent altitude can be made by choosing values of the respiratory quotient and the alveolar carbon dioxide appropriate to the semisteady or the steady states. The steady state calculations were given by Gray (1943), Brink (1944) and others, and were compared with those for the semisteady state by Bateman (1943) and Ferguson (1944).

(3) The calculations discussed in paragraph (2) were really predictions: well-founded predictions, to be sure, but it is a good thing to have them checked by reference to experimental data. The results of the comparisons fully confirm the conclusions that had already been drawn concerning the value of the different reference points for equivalent altitudes: the use of dry inspired gas as reference point is quite without theoretical or experimental justification, while "both the tracheal and alveolar methods showed excellent agreement with the experimental data. The superiority of one over the other could not be demonstrated experimentally, for the differences between them are slight." (Gray 1944 b). This conclusion is of direct application to the use of the idea of equivalent altitudes in standardizing oxygen equipment because reference curves were obtained from one group of subjects and the data for equivalent altitude determinations from other groups and from other methods of measurement.

(4) We should like to take this opportunity to express personal doubts as to the present value of the "equivalent altitude" idea. As to its value in the past, there can be no doubt; it works perfectly well in establishing the gas mixtures that must be breathed in order to avoid anoxia. When some anoxia is involved, I think that the idea should be abandoned excepting for the rough qualitative purposes of indoctrination. It should not be allowed to masquerade as a scientific concept which has any significant contribution to make to the physiology of high altitude flight. It is doubly undesirable in the first place, it has not yet been properly established that equal arterial saturation implies equal impairment under different conditions. In the second place, as we have seen,

---

\* to which Gray gives the name "unsteady state". We consider that some effort should be made to use a consistent nomenclature. See Helmholtz, Bateman and Boothby, 1944.

on the alveolar air basis involve not only the postulate concerning arterial saturation, but also secondary assumptions as to the level of the alveolar carbon dioxide pressure and - if the inspired gas is not pure oxygen - of the respiratory quotient. The usual assumption, and the only convenient one, is that altitudes are equivalent when alveolar oxygen and carbon dioxide are both equal. This simplifies the equations and a numerical solution can of course always be obtained. Thus it is mathematically possible for the postulated conditions to be fulfilled; but this does not prove that they will be fulfilled in practice. Available data suggest that they are not: in Fig. 3, following a suggestion from Fenn (1944), we have plotted alveolar oxygen against alveolar carbon dioxide for subjects breathing air, and pure oxygen at altitude, using Boothby's (Boothby 1944; Boothby and Baldes, 1944; and Figs. 1 and 2) data. We see at once that points of equal alveolar oxygen pressure are not in fact points of equal carbon dioxide pressure.

This is only one illustration of the general thesis that each particular anoxic state has its own peculiar set of biochemical and physiological data; to concentrate upon one variable and to ignore the rest is to endanger proper understanding of the physiology of anoxia. The use of equivalent altitudes is rather like saying that two patients, one a diabetic and the other suffering from tuberculosis, are equally sick because they will probably both take about the same time to die. The statement may be true, but it is not a useful one, and too much insistence upon it may delay the vital realization that there is more than one way of dying.

October 18, 1944

Prepared by J. B. Bateman  
Mayo Aero Medical Unit

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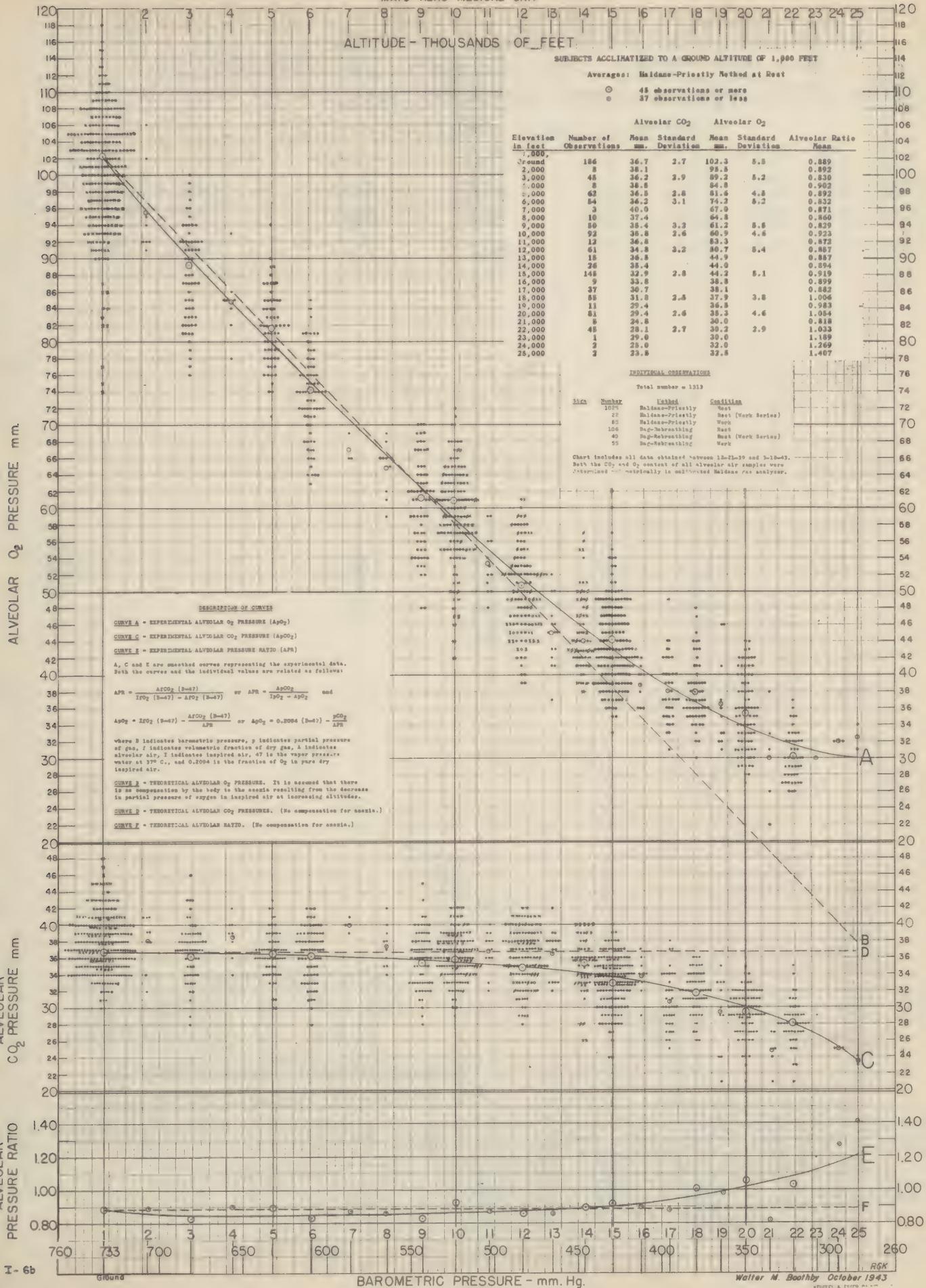
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ALVEOLAR O<sub>2</sub> and CO<sub>2</sub> PRESSURES and ALVEOLAR RATIOS at VARIOUS ALTITUDES WHILE BREATHING AIR

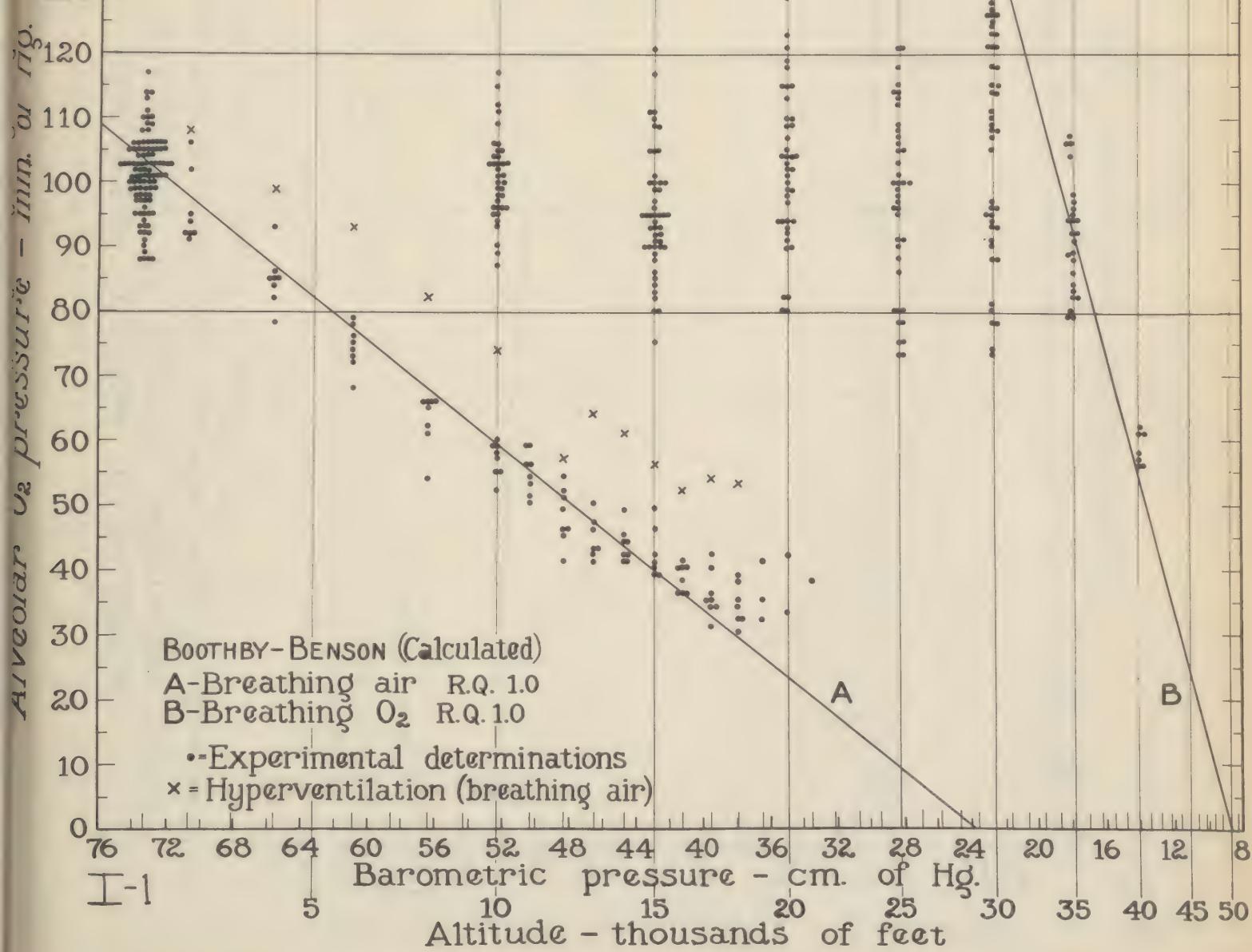
MAYO AERO MEDICAL UNIT



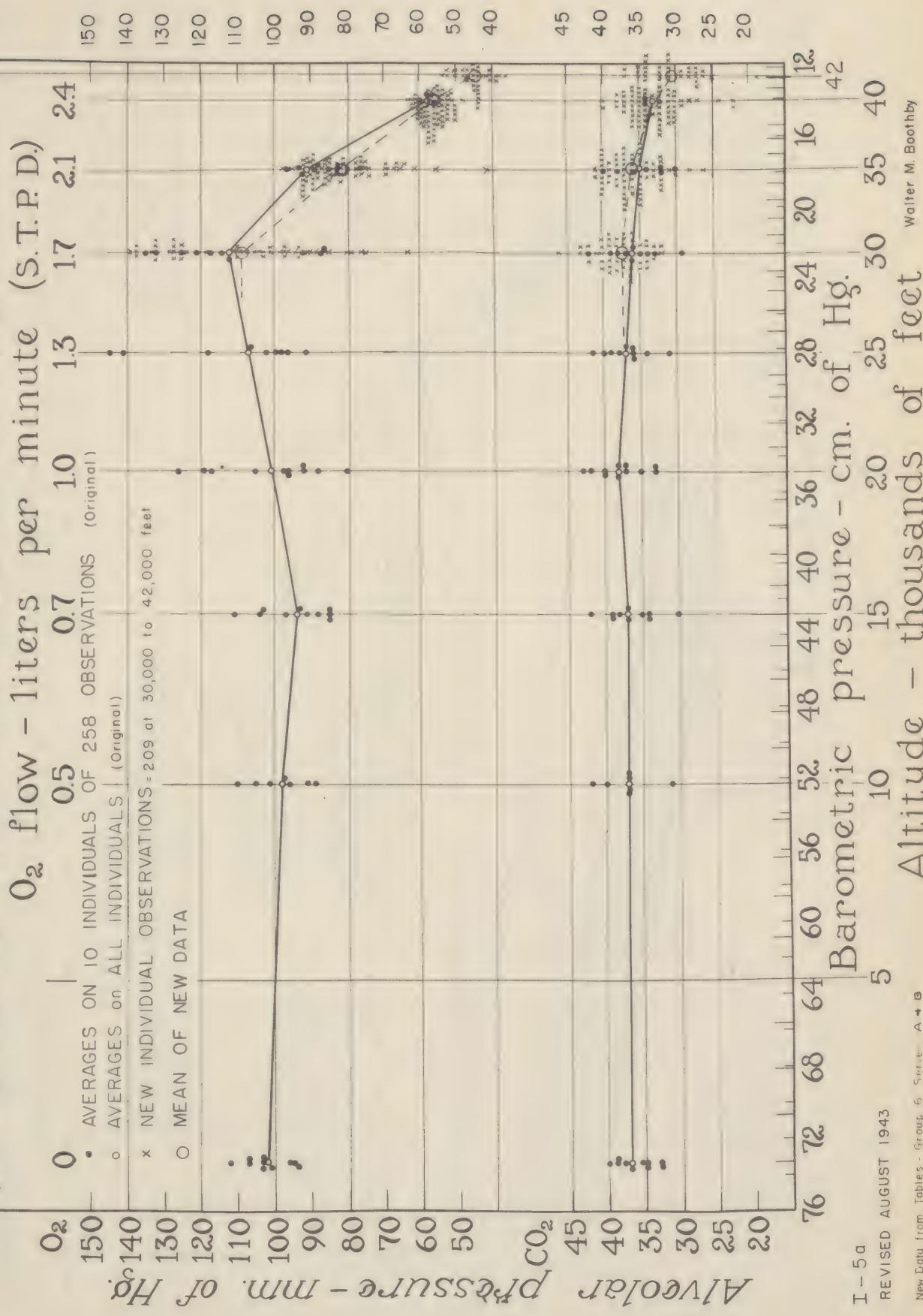
**ALVEOLAR O<sub>2</sub> PRESSURES - MM. OF HG.**  
**WHILE BREATHING AIR AND WHILE BREATHING OXYGEN AT STIPULATED RATES OF FLOW**

O<sub>2</sub> flow - liters per minute

S.T. P.D.	0.5	0.7	1.0	1.3	1.7	2.1	2.4
Bar - S.T. - Dry	0.73	1.24	2.18	3.51	5.78	8.93	12.94
Bar - 37°C - Dry	0.83	1.41	2.49	4.00	6.59	10.18	14.75
Bar - 37°C - Sat.	0.91	1.58	2.88	4.80	8.30	13.84	22.13



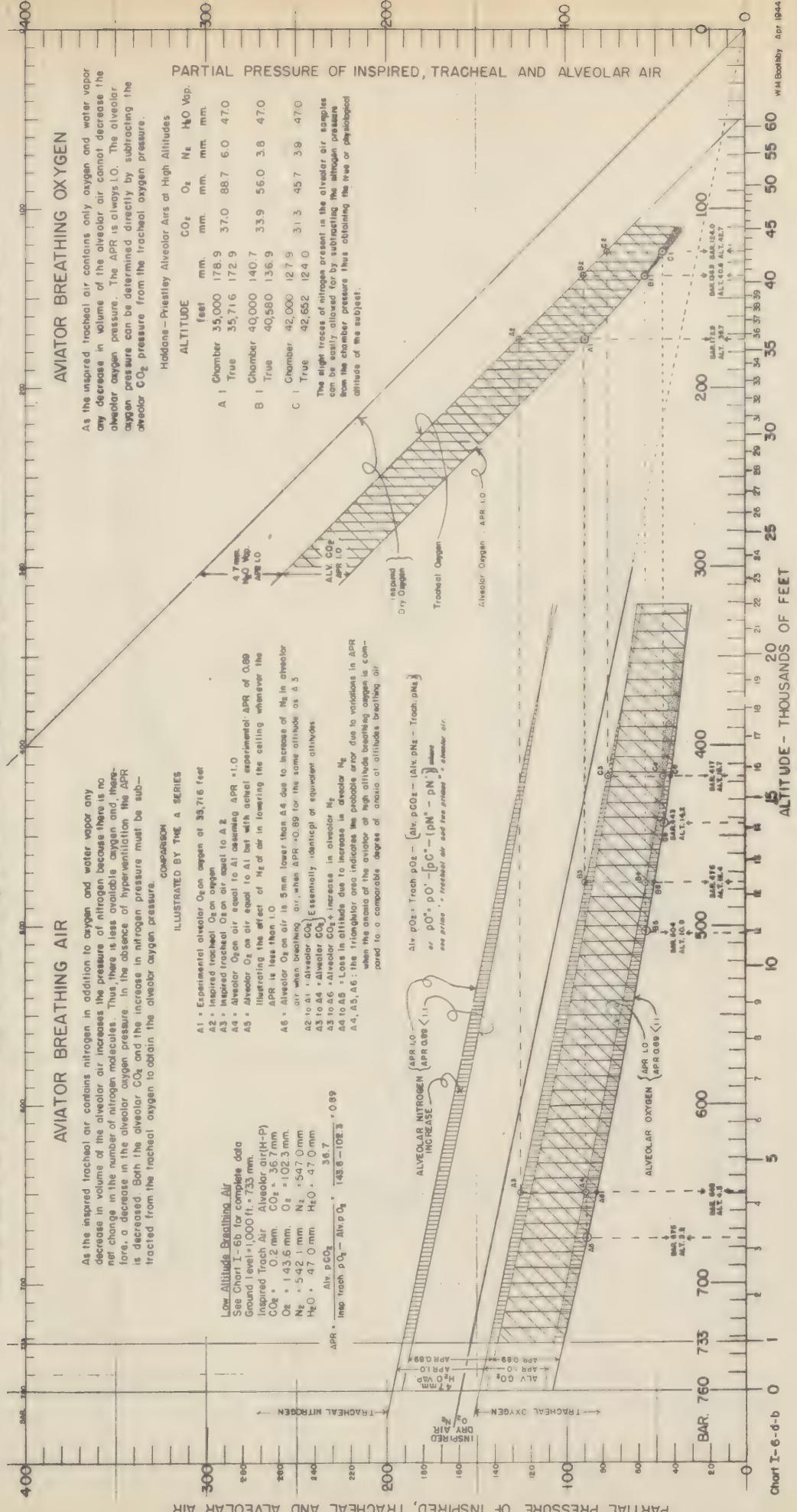
**ALVEOLAR  $O_2$  AND  $CO_2$  PRESSURES - MM. OF HG.  
WHILE BREATHING OXYGEN AT STIPULATED RATES OF FLOW  
(AVERAGE FOR EACH INDIVIDUAL AND AVERAGE FOR ALL INDIVIDUALS)**

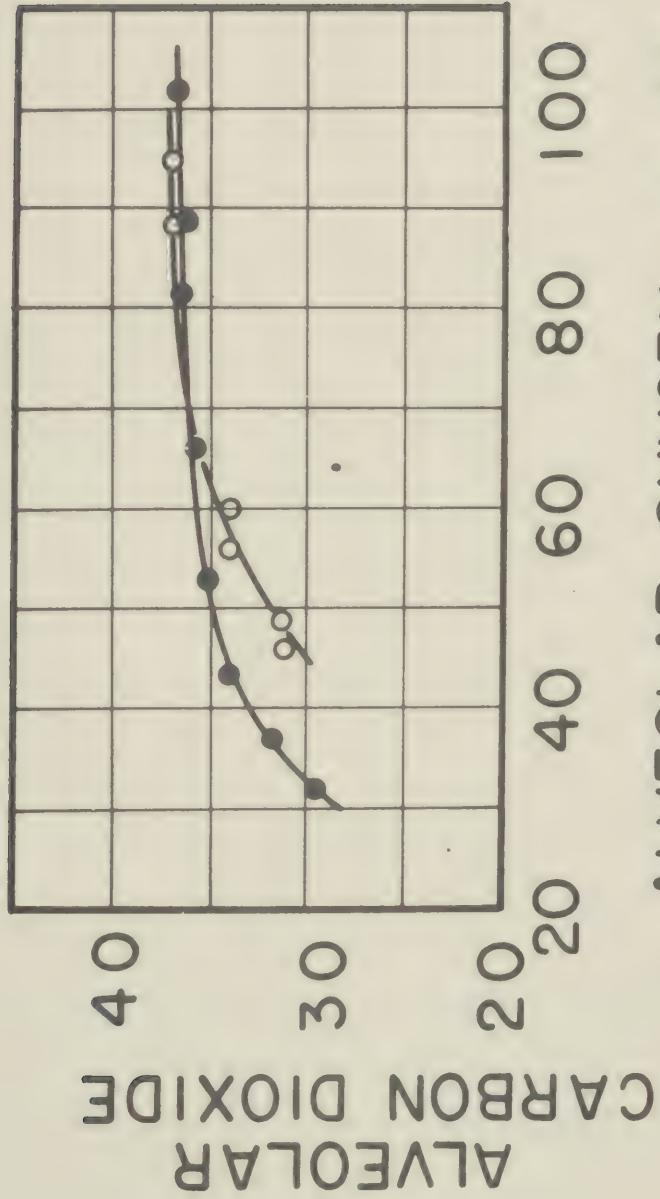


I-5a  
REVISED AUGUST 1943  
New Data from Tables - Group 6 Series A + B  
Walter M. Boothby

## COMPARISON BETWEEN LOW ALTITUDES BREATHING AIR AND HIGH ALTITUDES BREATHING OXYGEN

based on over 1400 determinations of the alveolar air by the Holdane - Priestley method on subjects acclimatized to ground level of 1000 feet





### ALVEOLAR OXYGEN, mm. Hg.

- SUBJECTS BREATHING AIR.
- SUBJECTS BREATHING OXYGEN.
- BOOTHBY'S DATA.

Mayo Aero Medical Unit.  
Chart I 8b.

J. B. Batteman.  
October 1944.



MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT  
to  
AIR TECHNICAL SERVICE COMMAND  
Under Contract No. AC-25829

**Subject:** Comments requested by Chief, Aero Medical Laboratory, Engineering Division, Wright Field, on: (1) "Adequacy of Reservoir Delivery Oxygen Systems," by Squadron Leader J. K. W. Ferguson; (2) "Optimum Sizes of Reservoirs for the Breathing of Oxygen," by Squadron Leader J. K. W. Ferguson; (3) "Evaluation of Constant Flow-Reservoir Oxygen Mask System for Use in Navy Transport Planes," Report No. Two, Naval Medical Research Institute Research Project X-391.

**Serial Report:** Series A, No. 10

**Date:** December 20, 1944

I. (1) The advantages and adequacy of a reservoir delivery oxygen system (constant flow) are well restated by Sq/L Ferguson. In summary we can state that we agree with all of his statements and conclusions. The points of emphasis are as follows:

(a) We approve the use of the "tracheal air basis."

(b) We agree that the "freezing problem" renders it advisable to use the bag only as a reservoir and not as a rebreathing bag. Therefore the A-8-B mask should be modified by providing a non-freeze type of valve to prevent expired air passing into the reservoir; also the opening and connection to the reservoir bag should be made larger to accommodate the valve.

(c) Without rebreathing the capacity of the reservoir bag of the A-8-B can be increased from 0.75 to 0.9 liters thus fulfilling all requirements up to 33,000 feet.

(d) Table I of the report contains valuable data on "Volume of inspiration and different rates of oxygen supply for inspired mixture to be equivalent to certain altitudes without added oxygen." This table will be found extremely helpful in estimating rates of oxygen flow needed under various combat and transport conditions.

(e) The best scale of oxygen supply can only be defined after the conditions in which the equipment is to be used has been determined; and it is also important that the characteristics of the regulator to be supplied be taken into consideration.

(f) Very moderate rates of oxygen supply will support large volumes of breathing and corresponding exertion provided minimum degrees of anoxia are permitted temporarily and manual adjustment will be rarely needed if proper scales of oxygen supply are provided especially if an aneroid type of regulator is used to compensate for altitude.

(We wish to add that an improved regulator should be designed which not only automatically compensates for altitude but also can be manually controlled for providing increased oxygen for hard work (emergency knob).)

(2) Sq/L Ferguson has made a very valuable series of calculations on the optimum size of the reservoir bag for various rates of oxygen flow at different altitudes with which we agree; these values are presented in his Table I.

(a) His calculation shows that an effective volume of the reservoir bag of 0.9 c.c. (instead of the 0.75 c.c. as now used in A-8-B) is optimum for altitudes above 28,000 feet. We agree that this increase in size is advisable if the bag is merely used as a reservoir without rebreathing as recommended by him. However, if rebreathing is to be permitted then the bag cannot be increased in size without discomfort to small individuals (nurses, etc.) who have a limited tidal volume; this is especially true when conservation of oxygen is needed at low altitudes. With a small reservoir rebreathing bag of 0.75 c.c. capacity some comfort is gained by the fact that rebreathing adds some moisture to the air; this fact, however, is a disadvantage at low altitudes in the tropics.

(3) Lt. Goldman has also presented a very constructive review of the continuous flow reservoir delivery system. His conclusions are in some points similar to, but less specific than, those reached by Sq/L Ferguson.

(a) Lt. Goldman found as a result of 78 observations on 17 subjects during flights that the average ventilation rate was 10.4 LPM, BTPD. It is to be noted that he expresses ventilation volume at BTPD (body temperature and pressure, dry) and not at BTPS (lung condition of body temperature and pressure saturated with moisture at 47 mm.). Both methods are, of course, correct; the latter method, BTPS, is on the whole more convenient because its respiratory volume is constant at all altitudes without anoxia as shown by Boothby, Lovelace and Benson (Journal of Aeronautic Sciences, September 1940).

(b) The chart on "Fraction Added Oxygen Required to Maintain Stated  $P_0_2$ " is excellent and a very convenient method of ascertaining equivalent altitudes for various oxygen flows.

II. Our own conclusion is that the constant flow delivery oxygen system, after the mask, valve, reservoir bag and regulator have been perfected, will be safer and more comfortable than the demand system and equally economical of oxygen in all transport and in many combat planes. In large planes it simplifies the problem of walking about. A slight positive pressure (safety pressure of 0.5 cm. water) can be easily and economically obtained at high altitudes (above 35,000 feet) to prevent inboard leak by simply increasing slightly the oxygen supply up to 2.5 liters per minute STPD. It is noteworthy that instructors and personnel connected with high altitude chamber indoctrination and research nearly always use the constant flow method in preference to the demand system when both methods are readily available.

Prepared by Walter M. Boothby, M.D.  
Mayo Aer. Medical Unit



MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT

to

AIR TECHNICAL SERVICE COMMAND  
Under Contract No. AC-25829

Serial Report: Series A, No. 11

February 7, 1945

Subject: Oxygen Requirements with Constant Flow Equipment  
(P. O. W(535)-ac-25829)

To: Chief, Aero Medical Laboratory, TSEAL-3C  
Aircraft and Physical Requirements Section  
Engineering Division  
Wright Field  
Dayton, Ohio

Attention: Colonel Lovelace

1. In reply to your letter of January 5, 1945 we are enclosing comments on Memorandum Report TSEAL-3-696-42H, subject as above, dated 30 December 1944.

2. According to your request I have reviewed and made some comments which are attached herewith as Appendix I.

3. I have also asked Dr. Bateman to make some comments on the mathematics involved in the report. These are attached as Appendix 2.

4. This is a good report and is important because a new method of study shows that the flow of oxygen needed for a constant flow system is the same as that previously shown to be necessary for the "5,000 foot" standard recommended by Wright Field for the demand system.

Walter M. Boothby, M.D.  
Mayo Aero Medical Unit

## APPENDIX 1

Comment on paper by Captain H. G. Swann: "Oxygen Requirements with Constant Flow Equipment," by Walter M. Boothby

1. The basic data in this paper while not extensive is excellent because a new method has been used to establish the flow of oxygen necessary to maintain a normal saturation of arterial blood at altitude.
2. At my request Dr. Bateman has gone over the formulas used by the author and found them correct; however, he suggested what appears to us an easier and clearer formulation.
3. I have made a new chart of Swann's data which shows more clearly the relationship of his data to previous recommendations of oxygen flow. Special attention is drawn to the fact that curve 1a (which is Swann's curve but calculated for a standard ventilation rate of 10 L/min. instead of 8.9 L/min.) is almost identical with curves 4 and 4' which are the "5,000 foot" AAF standard for demand regulators.
4. It is also to be noted that up to 20,000 feet it is practically identical with the standard suggested by Boothby, Lovelace and Benson in 1942. They, however, increased the flow at sitting rest for elevation above 25,000 feet to permit greater activity without necessity of resetting oxygen flow to the work scale.
5. It is suggested that the basic resting flow be made approximately corresponding to red line A for sitting rest.
6. It is suggested that the moderate work flow be twice the basic resting flow which will take care of a working condition of around 20 L/min. with real safety at the higher elevation.
7. It is suggested that the severe work flow be 4 times the basic resting flow. It is to be noted that this will safely allow for extreme work at 40,000 which might cause a ventilation rate of nearly 70 L/min. BTPS and still give the subject pure oxygen. At 35,000 feet the subject would have available 46 L/min. BTPS of pure oxygen. At 30,000 feet there would be available practically 30 L. of pure oxygen and thus permit work 3 times basal and still render pure oxygen available to subject.
8. It is suggested that a new constant flow aneroid controlled regulator be developed with three "speeds" so that by turning a knob the aviator can set the regulator to deliver any of the three rates of flow. If thought advisable, a fourth speed could be added.
9. The A-15 mask can be easily converted into a constant flow mask. To do this for preliminary tests attach an A-8-B connector to reservoir bag, add a tube with a standard single turret containing a small Cushnet valve for inspiration of air, and attach to demand inlet. Leave present demand expiratory valve in place in mask but remove the inspiratory cheek valves so as to permit some rebreathing into reservoir bag. To prevent spitting into inspiratory tubes use a protector similar to that now used over cheek valves. If possible, increase the thickness of both inspiratory and expiratory valves slightly to increase a little the pressure required to open the valves. This set up for the mask should prove very comfortable for constant flow especially as it need not be put on as tightly as when used as demand mask. After testing, slight modification and improvement will probably be found advisable.

MAYO AERO MEDICAL UNIT

Walter M. Boothby

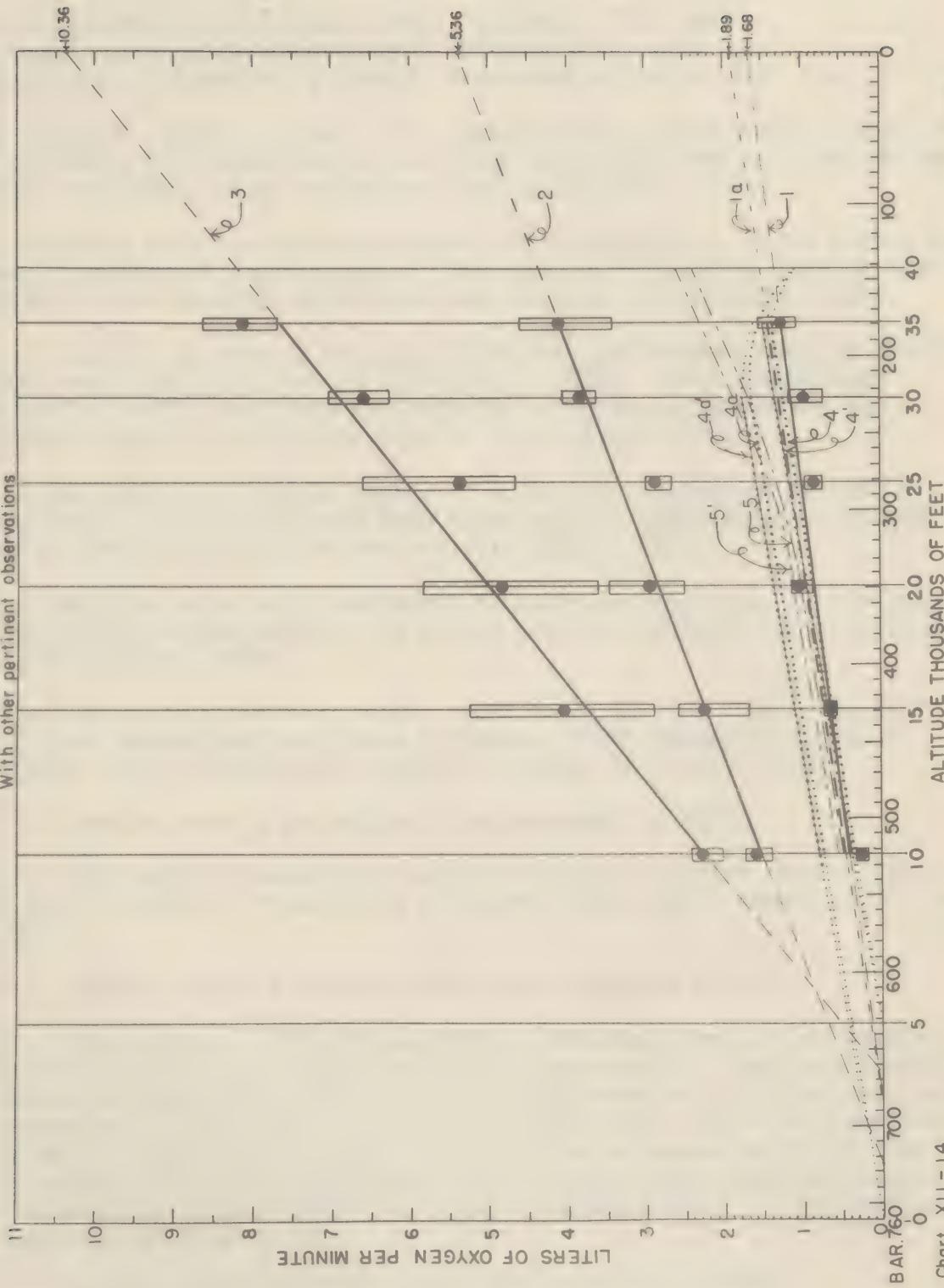
COMPARISON OF THE OXIMETER DATA OBTAINED BY

Capt. H.G. Swann

TSEAL 3-696 - 42 H

Dec. 30, 1944

With other pertinent observations



### LEGEND CHART XIII-14

STPD = Standard temperature and pressure, dry: 760 mm., 0° C, dry.

NTPD = Normal temperature and pressure, dry: 760 mm. 70° F, dry.

BTPS = Body temperature and ambient pressure, saturated with moisture: Bar. 37° C, Sat

Swann's data for curves 1, 2 and 3 are indicated by a large solid circle for the average of 3 determinations and the upper and lower of these determinations are indicated by the oblong block expressed at NTPD.

Curve 1 - Oxygen flow required for subject at sitting rest. Curve fitted to data by method of least squares. The average ventilation rate of same subjects under similar conditions was found to be 8.9 L/min., BTPS.

Curve 1a - Similar to curve 1 but calculated for the standard resting ventilation rate at sitting rest of 10.0 L/min., BTPS. (This allows easy comparison with other data the majority of which is calculated for a standard resting ventilation rate of 10.0 L/min., BTPS.)

Curve 2 - Subjects on a bicycle ergometer doing work equivalent to 2400 ft. lbs./min. The same subjects when doing similar experiments at ground level had an average ventilation rate of 26.4 L/min., BTPS.

Curve 3 - Subjects doing work equivalent to 4200 ft. lbs./min. In similar experiments on same subjects at ground level the average ventilation rate was 40.7 L/min., BTPS.

Curve 4 - "5,000 foot" standard oxygen requirement for the demand regulator. The curve represents the liters of oxygen, STPD, needed to maintain tracheal  $pO_2 = 123$  mm. with subject breathing 10 L/min., BTPS.

Curve 4' - Same as curve 4 but oxygen flow expressed at NTPD.

Curve 4a - "Sea level" standard for demand regulator. Liters oxygen, STPD, needed to maintain tracheal  $pO_2 = 149$  mm. with subject breathing 10 L/min., BTPS.

Curve 4a' - Same as curve 5 except oxygen flow expressed at NTPD.

Curve 5 - Liters oxygen, STPD, recommended by Boothby, Lovelace and Benson for use with constant flow BLB mask (750 cc. reservoir). Their recommendation corresponds approximately to a "4,000 foot" standard to 20,000 feet and increasing to "sea level" standard at 30,000 feet. Above this altitude oxygen flows increased to 2.4 L STPD to give an excess at 40,000 feet for safety. Note in attached chart that these oxygen flows maintained an essentially normal alveolar  $pO_2$  up to 40,000 feet on a large number of subjects at sitting rest.

Curve 5' - Same as curve 5 except oxygen flow expressed at NTPD.

Comment on paper by Captain H. G. Swann: "Oxygen Requirements with Constant Flow Equipment."

## APPENDIX 2

Comment on paper by Captain H. G. Swann, "Oxygen Requirements with Constant Flow Equipment," by J. B. Bateman

The author made the following measurements:

- (1) At various altitudes: subjects at rest, or working at the rate of 2,400 or 4,200 foot lb./ minute: oxygen flow in constant flow regulator required to maintain oximeter readings at 95 per cent.
- (2) At ground level (presumably): pulmonary ventilation rates on these subjects (a) at rest, (b) doing 2,400 ft. lb./min., (c) doing 4,200 ft. lb./min.

By simple steps he derives from this data a formula giving the oxygen flow required at any altitude for the performance of a given task in terms of the ventilation rate required when the task is performed at 10,000 feet. The argument could have been made clearer by graphical illustration and by a simpler algebraic statement. It is essentially as follows:

(1) The curves for oxygen flow,  $y$ , against barometric pressure,  $P$ , are straight lines for subjects at rest or at work. The lines obtained all converge very roughly to a single point around  $P = 700$  mm. (Fig. 1). Consequently, at any given pressure or altitude the flows required vary in the same ratio for different rates of work. Therefore, if we select the flow required at a standard altitude, such as 10,000 feet, as unity, all the curves obtained for different rates of work can be combined into a single line. The equation for this line is:

$$y = y_{10} (4.23 - 0.00616 P) \quad (1)$$

(2) The measurements of ventilation rate when compared with the measurement of oxygen flow show that with increasing severity of work the latter increases more rapidly than the former (Fig. 2). The author first assumes that they both increase at the same rate: we may say

$$\frac{y(\text{work})}{y(\text{rest})} = \frac{V(\text{work})}{V(\text{rest})} \quad (2)$$

He then tries to correct this by writing

$$\frac{y(\text{work})}{y(\text{rest})} = 1.27 \frac{V(\text{work})}{V(\text{rest})} \quad (3)$$

which is roughly true for the data in Fig. 2.

Now taking 10,000 ft. as our standard altitude, we know (by measurement) that

$$\begin{aligned} y(\text{rest})(10,000 \text{ feet}) &= 0.384 \text{ liters/min.} \\ \text{and } V(\text{rest})(10,000 \text{ feet}) &= 8.9 \text{ liters/min.} \\ \therefore y(\text{work})(10,000 \text{ feet}) &= V(\text{work})(10,000 \text{ feet}) \times \frac{0.384}{8.9} \times 1.27 \end{aligned}$$

or

$$y_{10} = 0.0549 V_{10} \approx 0.0549 V_0$$

since  $V$  probably does not vary with altitude if the oxygen supply is adequate.

Putting this in equation (1)

$$y = 0.0549 V_o (4.23 - 0.00616 P) \quad (4)$$

$$\text{or } y = V_o (0.232 - 0.000338 P) \quad (5)$$

which agrees substantially with the equation used by the author.

Comment

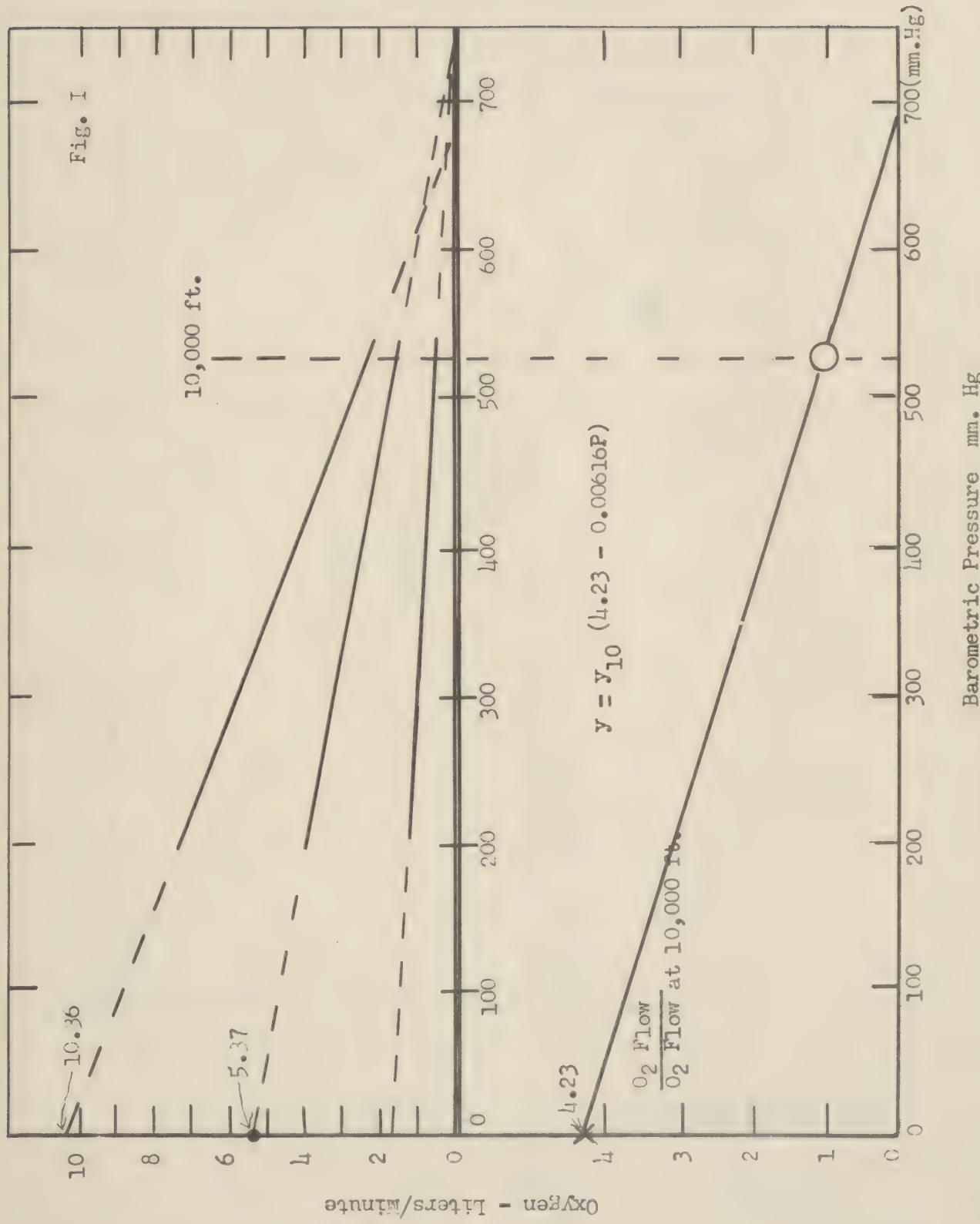
(1) The formula derived, as equation (5) above, from the experimental data given in this paper, purports to be a useful way of computing the flow of pure oxygen required at any given altitude between 10,000 and 35,000 feet by a person performing a given task involving muscular work. The only information required for the calculation is (a) the barometric pressure and (b) the pulmonary ventilation rate when the specified task is performed at a standard altitude of 10,000 feet.

(2) The author states that "when this formula is used to compute the expected oxygen requirement at the various altitudes and conditions of work, it is found that the computed values agree with the observed average values within 10% - at the work levels of 2,400 and 4,200 feet pounds per minute. At rest, however, the computed values on the average are around 30 per cent greater than the observed values." This is argument in a circle, since the formula is being applied to the data from which it was derived. The 30 per cent discrepancy at rest is merely the result of introducing the factor 1.27 in obtaining equation (3).

(3) Obviously a formula of this kind needs confirmation over a wider range of conditions. It might be useful to extend the measurement of ventilation rates over a wider range of rates of working, to check the behavior at several altitudes, and perhaps to obtain a new formula of wider applicability, assuming, of course, that the information is still needed for practical reasons - a matter upon which I cannot judge.

(4) The report does not state quite clearly nor in sufficient detail how the flow was adjusted to give an oximeter reading of 95%. The oximeter is somewhat insensitive in this region and the flow readings might be expected to show a rather wide scatter. Were the values measured in each case the lowest that would give the desired oximeter reading during a gradual increase in flow?

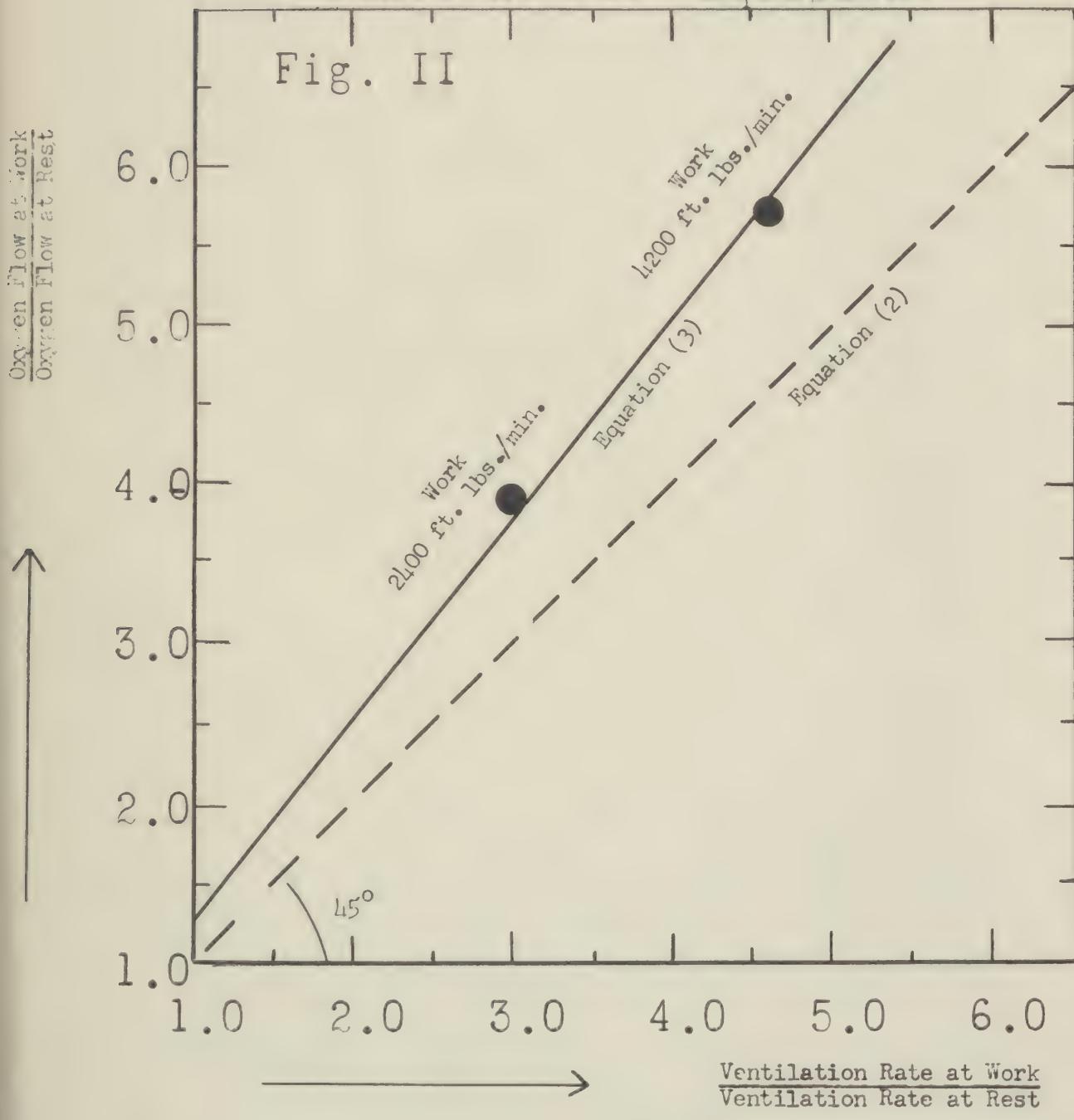
COLLINIT ON SWANN'S PAPER ON OXYGEN REQUIREMENT WITH  
CONSTANT FLOW EQUIPMENT



J. B. Batteman Jan. 1945

Chart XII 14a

Comments on Swann's Paper  
on Oxygen Requirements with  
Constant Flow Equipment



J. B. Bateman

Jan. 1945  
Chart XII 14b



NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

acting for the

COMMITTEE ON MEDICAL RESEARCH  
of the  
Office of Scientific Research and Development

COMMITTEE ON AVIATION MEDICINE

Report No. Series A, No. 12  
Date 28 May 1945

EFFECTS OF INCREASED INTRAPULMONARY PRESSURE ON DARK ADAPTATION. By Charles Sheard,  
Mayo Aero Medical Unit, Rochester, Minnesota. (OSRD contract: OEMcmr-129)

ABSTRACT

The present studies on the effects of increased intrapulmonary pressure on the threshold levels of cone and rod adaptation show that, using positive pressures of 4 or 8 inches water (7.5 and 15 mm. mercury pressure) at high altitudes (from 36,000 feet), there is a maintenance of maximal sensitivity to light and of the best levels of rod and cone adaptation which are possible under the conditions imposed. At high altitudes (42,000 to 45,000 feet), without increased intrapulmonary pressure, there may be a change of 0.75 to almost 1 log unit in the rod threshold, indicating a five- to tenfold increase in the amount of light needed to produce a response as compared to the threshold values at ground level. In general, there is less effect of pressure breathing on the cone adaptation than on the rod adaptation, since there is a greater effect of anoxia per se on the rods in the periphery than on the cones at the macula. These investigations show that, with increased intrapulmonary pressure at high altitudes, it is generally possible to maintain the threshold levels of rods and cones at the same values respectively as were obtained initially at ground levels breathing air or at altitudes under 30,000 feet while breathing oxygen.

NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

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COMMITTEE ON AVIATION MEDICINE

Report: Series A, No. 12  
Date; 28 May 1945

EFFECTS OF INCREASED INTRAPULMONARY PRESSURE ON DARK ADAPTATION.\* By Charles Sheard,  
Mayo Aero Medical Unit, Rochester, Minnesota. (OSRD contract: OEMcmr-129)

REPORT

Introduction

It is known that there are three fundamental elements which may exert an influence on dark adaptation. These factors are: (1) Pigment or pigments and the conditions that may affect the photochemical reactions; (2) metabolism and nutritional state, both of the body and of the retina as a localized site of photochemical changes, and (3) neural and cerebral responses which are exhibited so strikingly in anoxia and certain aeromedical problems. It is possible to control and thereby either evaluate or eliminate changes in the first two factors through the use of certain (red) pre-adapting goggles or sufficiently long periods of dark adaptation, on the one hand, followed by the collection of data on the course and levels of cone and rod dark adaptation with the subjects in a basal or other desired metabolic state. Through the employment of such controls it is possible to obtain data which, under any set of imposed conditions, will be reproducible (within about 0.1 to 0.2 log unit) from day to day. Also in this manner, it is possible to demonstrate changes in visual adaptation which otherwise would be either obscured or variable in character.

Nervous tissue has been shown to be particularly sensitive to a deficit of oxygen. Consequently it is not surprising that investigation of certain functions which involve the retina has revealed that these also manifest extensive changes on exposure of the subject to low oxygen tension. Certain visual characteristics, such as sensitivity to light, are affected more easily than other functions. Investigation indicates definitely that measurements of light sensitivity offer one of the most delicate methods for obtaining information regarding the initial as well as the final effects of anoxia. Subsequent to the administration of low oxygen mixtures (8 to 12 per cent of oxygen) there is a decrease of retinal sensitivity which varies somewhat in different subjects, with a restoration to normal levels upon the administration of oxygen. Since these changes also take place in thoroughly dark-adapted subjects, destruction of visual pigments or a delay in their regeneration cannot be involved in all probability.

\* A rather complete review of the literature, methods, procedures and important investigations on dark adaptation to 1944 is to be found in an article by Charles Sheard on "Dark Adaptation: Some Physical, Physiological, Clinical and Aeromedical Considerations" in the Journal of the Optical Society of America, 34:464-508 (August) 1944.

It is therefore highly probable that all factors and effects either may be ruled out or else adequately controlled, to the end result that the neural or cerebral responses only are of concern in anoxia, whether this be at relatively low altitudes breathing air or at very high altitudes breathing oxygen under pressure. In either case, with the arterial oxygen saturation reduced, let us say, to 80-85 per cent, there may be a general narrowing and darkening of the visual fields and increased visual dysfunction. For many years it has been known that the use of oxygen at altitudes above 10,000 feet or thereabouts was generally advantageous in preventing various visual and cerebral effects. In recent years, when flying to altitudes of 40,000 feet or more has been indulged in, it is known from both theoretical grounds and practical experience that the breathing of pure oxygen per se is not sufficient since, at such high altitudes, arterial oxygen saturations decrease with the same resultant trains of symptoms and effects as would occur at much lower altitudes breathing air. Hence the purpose of the present study was to investigate the cone and rod thresholds of certain subjects, breathing air and oxygen on separate occasions, at various altitudes ranging from ground level to 15,000-18,000 feet. Later four of these same persons were used in the investigations on the effects of increased intrapulmonary pressure at altitudes at which the partial pressure of the oxygen in the alveoli, when the subject was breathing pure oxygen, would be the same as the partial pressure at lower atmospheric pressure when he was breathing air.

#### Methods

The experimental ensemble consists of a suitable optical bench about two meters in length which could be attached to and permanently aligned with a satisfactory line of sight, ultimately assumed by the subject, within the low pressure chamber. A suitable light source, neutral filters and accessories such as are used commonly in connection with an adaptometer were employed. To the window of the decompression chamber there was fastened by suitable clips a blackened metallic plate carrying several apertures into any one of which could be inserted a small lamp with red filter to serve as a suitable fixation point. These apertures were 1, 5, 10 and 15 degrees, respectively, from the target or retinal stimulus area used in obtaining the course of dark adaptation and threshold levels of either the cones (1 degree from stimulus area) or rods (10 or 15 degrees paramacular location). The subject was comfortably seated inside the chamber and at a distance of a meter from the plate carrying the red fixation light and the retinal stimulus area. The size of the retinal area under test was 0.5 degree throughout this study. The subject generally wore standard red goggles during the period of preparation for a given experimental test. On occasion, however, the subject was light adapted (generally with a background intensity of 300 millilamberts and for four minutes) and the course of dark adaptation determined prior to ascent to any desired simulated altitude or, again, at that altitude. The data given in connection with Figures 1 to 4 inclusive indicate the course of procedure and the time consumed in each portion of the test. Suitable masks and positive pressure breathing ensembles were available and an attempt was made to select such equipment as would afford the wearer the greatest degree of comfort possible under the conditions imposed.

#### Experimental results

Table 1 contains data on the cone and rod adaptation of the same subject at various barometric pressures (simulated altitudes) with air and with oxygen. The greatest improvement in cone threshold (given in Table 1) with the breathing of oxygen (15,000 feet) is 0.3 log unit. The corresponding maximal change in rod threshold is 0.6 log unit, indicating a fivefold change in the light threshold when

breathing air as compared to the value when breathing oxygen. In general, the breathing of oxygen maintains the cone and rod adaptations at the same levels respectively as are demonstrated at ground levels when breathing air.

The breathing of oxygen is adequate to maintain normal arterial oxygen saturation until altitudes of about 36,000 feet are reached. The arterial oxygen saturation, breathing air at an altitude of 11,000 to 12,000 feet, is 85 per cent on the average. Various investigations have indicated the effects of such reductions in arterial oxygen on reaction time, ability to carry on mental tasks and, in our report, on thresholds of dark adaptation. When breathing pure oxygen it is possible to show theoretically and demonstrate experimentally that the oxygen saturation will be between 80-90 per cent or even less at altitudes about 42,000 feet. Since subjects vary in their light sensitivity at various relatively low altitudes, it might be anticipated that there would be a spread in the range of altitudes at which various individuals would demonstrate minimal and yet definite changes in cone and rod adaptation with pure oxygen at high altitudes. This range of altitude would be expected to extend from 36,000 to 40,000 feet on the basis of the experimental results obtained on subjects breathing air at altitudes ranging from ground level to 15,000 feet. Making use of Doctor Boothby's chart on the comparison between low altitudes breathing air and high altitudes breathing oxygen, it would be expected that if the subject showed a change of 0.25 log unit in rod threshold at an altitude of 9,000 feet (at which altitude the partial pressure of alveolar oxygen would be 63 mm. mercury) there would be about the same change in threshold when breathing oxygen at an altitude of 39,000 feet, since the partial pressure of the alveolar oxygen would be the same at the two designated altitudes. With increased intrapulmonary pressure there should be an increase in the partial pressure of oxygen in the alveoli and a greater uptake of oxygen and therefore a restoration of or improvement in the levels of dark adaptation, dependent on the arterial oxygen saturation.

Data illustrative of the effects of increased intrapulmonary pressure on the threshold levels of rod and cone adaptation are given in Figures 1 to 4 inclusive. In these investigations the same general order of experimental procedure was followed. The subject was dark adapted for at least 30 minutes prior to obtaining data on the dark adaptation levels with the subject in the low pressure chamber and at ground level breathing oxygen. Pressure breathing under 4 and 8 inches water pressure (7.5 and 15 mm. mercury pressure) was instituted at any altitude desired and maintained throughout the course of the investigation. The lowest of the three curves in Figure 1 shows the course of the maintenance of dark adaptation of a subject at 15,000 feet breathing oxygen with and without increased intrapulmonary pressure. Under these conditions there is no effect of pressure breathing on the thresholds of dark adaptation. The course of the changes in dark adaptation at 37,500 feet with and without pressure breathing are given in the middle curve of Figure 1. Without increased intrapulmonary pressure there is a rise in the level of rod adaptation from a value of about 50 micromillilamberts to 200 micromillilamberts, hence a fourfold increase in minimal light stimulus observed. The use of pressure breathing under 4 or 8 inch water pressure produced a restoration to the lowest and, therefore, the best levels of dark adaptation. The course of rod response of a subject in whom the logarithm of the threshold in micromillilamberts was initially 2.20 (or 160 micromillilamberts) is given in the upper curve of Figure 1. The subject was taken to an altitude of 42,000 feet and without increased intrapulmonary pressure showed a rise in threshold level from 2.20 to 2.90 log units or 0.7 log unit change, indicating a fivefold increase in the amount of light needed

to produce a response. The use of pressure breathing restored the dark adaptation to its original levels and therefore enabled the subject to maintain the same degree of night vision as had been obtained at ground level.

Other experimental results are given in Figures 2, 3 and 4. Ordinarily the retinal stimulus area was located 10 degrees above the macula. In this instance it was placed at 15 degrees temporally. Also the levels of cone adaptation at the macula were obtained during the course of these tests at ground level and at 43,000 feet with and without pressure breathing. There is a change in cone thresholds from 3.2 to 3.5 log unit (or from 1,600 to 3,200 micromillilamberts), hence a twofold increase in light stimulus without increased intrapulmonary pressure. The level of rod adaptation is changed from about 65 micromillilamberts to 320 micromillilamberts, or a fivefold increase in the light required, without pressure breathing, and a return to the original values with 6 inch water pressure (11.2 mm. mercury). These and similar data indicate that there is less effect of increased intrapulmonary pressure on the cone adaptation than on the rod adaptation (vide Figures 3 and 4), since there is a greater effect of anoxia per se on the rods in the periphery than on the cones at the macula.

#### Conclusions

The present studies on the effects of increased intrapulmonary pressure on the threshold levels of cone and rod adaptation show that, using positive pressures of 4 or 8 inches water (7.5 and 15 mm. mercury pressure) at high altitudes (from 36,000 feet), there is a maintenance of maximal sensitivity to light and of the best levels of rod and cone adaptation which are possible under the conditions imposed. At high altitudes (42,000 to 45,000 feet, without increased intrapulmonary pressure, there may be a change of 0.75 to almost 1 log unit in the rod threshold, indicating a five- to tenfold increase in the amount of light needed to produce a response as compared to the threshold values at ground level. In general, there is less effect of pressure breathing on the cone adaptation than on the rod adaptation, since there is a greater effect of anoxia per se on the rods in the periphery than on the cones at the macula. These investigations show that, with increased intrapulmonary pressure at high altitudes, it is generally possible to maintain the threshold levels of rods and cones at the same values respectively as were obtained initially at ground levels breathing air or at altitudes under 30,000 feet while breathing oxygen.

Table 1

CONE AND ROD DARK ADAPTATION THRESHOLDS AT VARIOUS  
ALTITUDES WITH AIR AND WITH OXYGEN\*

	Macula		10° Paramacula (1/2° stimulus area)	
	Air	Oxygen	Air	Oxygen
Ground (1000 feet)	3.62	3.61	1.57	1.51
Ground (1000 feet)	3.62	3.58	1.57	1.50
5000 feet	3.64	3.56	1.66	1.45
Ground (1000 feet)	3.43	3.16	1.67	1.48
10,000 feet	3.45	3.24	1.92	1.37
Ground (1000 feet)	3.36	3.24	1.55	1.37
15,000 feet	3.49	3.18	2.00	1.38

\* The values in the tables are the logarithms of the dark adaptation threshold intensities in micromilli-lamberts.



Mayo Aero Medical Unit

Walter M. Boothby, M.D., Chairman

REPORT: Series B, No. 1 July 25, 1942

Report by Charles Sheard, Ph.D., Capt. J. W. Brown, (MC), Kenneth G. Wilson, M.D.

on

Dark Adaptation

Abstract of first three of several proposed reports to be made concerning the effects of high altitude and anoxia upon visual functions. These first three reports concern the work done thus far upon dark adaptation.

I. Apparatus and Methods.

Subjects were seated inside the low pressure chamber 150 cm. from the stimulus area. Both eyes were used and no attempt was made to control pupil size. Light adaptation of 600 millilamberts was used for four minutes. Then using the stimulus area of 1/3 degree readings were obtained in total darkness. Readings of macular adaptation were taken every 30 seconds for 5 minutes, the subject fixing on a pin-point red light directly above the stimulus area. The fixation light was moved to a position 10 degrees paramacularly at the end of 5 minutes. Readings were then continued until the end of 25 to 30 minutes in darkness. A constant stimulus light of 20 foot candles was used which slides along a steel rail toward the stimulus area. When necessary the intensity of this light was reduced by a Wratten filter. The distance in centimeters from the point where the stimulus light first became visible to the stimulus area can be read off the scale beneath the steel rail. Applying the inverse square law the actual intensity of light required to be just visible at any time can then be calculated and is used on a logarithmic scale for plotting our curves. All subjects wore an aviation type B.L.B. mask at all times whether breathing air or oxygen at ground levels or at simulated altitude.

II. Effects of Anoxia.

At various simulated altitudes dark adaptation curves were obtained with the subject breathing air. After reaching an apparent level of paramacular adaptation oxygen was administered. After a new level was reached while breathing oxygen, the oxygen was turned off and the subject again breathed air. The course of dark adaptation levels in both macular and paramacular areas is speeded up and the levels of dark adaptation are improved when oxygen is administered at atmospheric levels extending from ground level (1000 feet here in Rochester, Minnesota) to 18,000 feet.

III. Effects of Fasting and of High Carbohydrate Meals on the Courses and Threshold Values of Dark Adaptation Obtained at Ground Levels, Using Air and Oxygen.

Anoxia, hunger and fatigue all play a roll in decreasing the ability of aviators to see in the dark. Even at the moderate altitude of 1000 feet above sea level (which is ground level at the Mayo Clinic, where these studies were made),

in order that an individual may attain his maximum ability to see in the dark he should eat a meal high in carbohydrate content and be breathing 100 per cent oxygen.

Our results show that the ability to see in the dark decreases with increase in altitude as a result of progressive anoxia, excessive fatigue, or lack of adequate food.

Our data show that an observer, having complied with these two requirements (namely, oxygen and food), even though fatigued and flying at any altitude, will be better equipped to become as quickly adapted to the dark as possible and to attain his best levels of dark adaptation.

#### Summary.

1. In fasting subjects, there is a definite improvement in the dark adaptation level obtained while breathing oxygen over that obtained while breathing air.
2. In fatigued subjects, there is an even more decided advantage in the use of oxygen as compared to air in the final levels of dark adaptation obtained.
3. The amount and type of food eaten prior to dark adaptation tests profoundly influence the final level attained. A light meal of very high carbohydrate content appears to be quite effective in increasing the ability to see in the dark.

#### Recommendations

1. That the flight crews on night missions be required, whenever possible, to make use of oxygen from ground levels and to continue the use of oxygen until return to ground, especially if landing is made at night.
2. That the crew shall be provided with light (not bulky) high carbohydrate meals (approximately 1000-2000 calories) about an hour before take-off time. It is further recommended that if the flight is to last for five to six hours or more, the crew be provided with concentrated carbohydrate food for ingestion while en route.
3. That flight crews be impressed with the necessity of adequate rest before any flight is undertaken.

MAYO AERO MEDICAL UNIT

Walter M. Boothby, M. D.,  
Director

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D A R K   A D A P T A T I O N

I. Apparatus and Methods.

Charles Sheard, Ph. D., Captain J. W. Brown, M.C.,  
and Kenneth G. Wilson, M. D.

II. Effects of Anoxia.

Charles Sheard, Ph. D., Captain J. W. Brown, M. C.,  
and Kenneth G. Wilson, M. D.

III. Effects of Fasting and of High Carbohydrate Meals on  
the Courses and Threshold Values of Dark Adaptation  
Obtained at Ground Levels, Using Air and Oxygen.

Charles Sheard, Ph. D., and Kenneth G. Wilson, M. D.

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Rochester, Minnesota

Report prepared June 15, 1942.

## DARK ADAPTATION

### I. Apparatus and Methods

Charles Sheard, Ph.D.,  
Captain J. W. Brown, M.C.  
and  
Kenneth G. Wilson, M.D.

Mayo Aero Medical Unit

#### A. Ensemble of apparatus

The subject under test is seated inside the low pressure chamber (with the doors always closed) at a distance of 125 centimeters from the glass window in the door of the chamber. The subject sits on a pillow-covered backrest with a head rest so placed that his eyes are on a horizontal line with the stimulus area. This seating arrangement is comfortable enough so that even after an hour of testing the subject does not complain of fatigue due to his position in the chamber (Fig. 1)

The apparatus used in our experiments enables the examiner to remain outside of the low pressure chamber during any test run. The optical bench used consists of a steel rail 150 centimeters in length with a centimeter scale attached directly beneath the rail. The proximal end of the bench fits into a grooved steel support directly under the window in the door of the low pressure chamber. The distal end of the bench is supported by a suitable metal standard resting on the floor and permanently fixed so the optical bench is horizontal and always in alignment at a 90 degree angle to the plane of the glass window.

A square metal box carrying the light source used to illuminate the stimulus area slides along the optical bench. Standard neutral Wratten filters may be slipped into the flanges on the front of the light box whenever it is necessary to reduce the intensity to  $1/10$ ,  $1/100$  or  $1/1000$  of its normal value. The light used for illuminating the retinal stimulus area is an ophthalmoscopic bulb whose intensity (at a distance of 1 centimeter) is maintained constant at 20-foot candles. The stimulating light source is moved along the steel rail (from its resting position at the distal end) towards the stimulus area until the subject signals that he is conscious of the presence of a light. The distance in centimeters from the illuminated stimulus area to the point where the source of such illumination is stopped during any test may then be read off the scale placed directly beneath the rail. Employing the inverse square law (since measurements are made of the distance from the stimulus light to the stimulus area) the actual intensity of light in the stimulus area which is just perceptible at any time during the course of the dark adaptation may be calculated.

Two steel flanges are permanently attached on either side of the window of the chamber, thus permitting the box with incandescent lamps used for glare-out (or light adaptation) purposes to be slipped into place over the window as well as allowing it to be quickly removed. In testing the levels of dark adaptation it was found satisfactory to cover the window of the chamber with a metal plate which also slipped into the flanges. This plate contains a round opening about 3 centimeters in diameter situated in the lower portion over which can be fitted metal caps carrying various sizes of circular apertures. The

diameters of these apertures are of such values that, when the subject's eyes are 125 centimeters from the stimulus area, there is subtended an angle at the retina of  $1/4$ ,  $1/3$ ,  $1/2$ , or 1 degree respectively. These apertures are covered with white paper of which the percentage transmission of light is known (about 10 per cent) and which possesses no appreciable color factor and is, therefore, neutral. Directly above and almost touching the metallic caps carrying the stimulus area is a tiny hole (1 mm.) covered with red glass, through which the subject views the light used for fixation purposes (operator's). On the outer side of the metal plate are a series of four sockets into any of which, as desired, a suitably mounted ophthalmoscope bulb fits. This ensemble constitutes the fixation source. By a proper vertical distribution of the receptacles for the fixation source on the metal plate, it is possible to follow the courses of dark adaptation at areas situated 5, 8, or 10 degrees paramacularly. This ensemble permits the examiner, who is located outside of the chamber, to change quickly the position of the fixation source and thus survey retinal responses in various areas.

The subject can control the intensity of the red fixation light by means of a rheostat placed inside the chamber. He is instructed to reduce the intensity of the red light as he becomes adapted to the dark, so that the fixation light is just visible. (The rheostat can be seen in Figure 1 beside subject's right knee.) There is also another rheostat located outside the chamber and so connected by a switch that, should the chamber rheostat fail to operate during the course of an experiment, the examiner can dim the fixation light by means of the control outside of the low pressure chamber.

#### B. Technic

An intercommunication system enables the examiner to hear the subject at all times, while a cut-in switch allows the examiner to give directions to the subject.

The subject is seated in the low pressure chamber with the fixation light rheostat at hand. He is provided with a small metal rod with which to tap on the side of the tank to signal the examiner.

After the chamber door is closed, the person operating the chamber controls the evacuation of chamber air to the desired simulated altitude. The subject is then allowed to remain at this altitude for six minutes. At the end of six minutes' time all chamber windows and the entire room are blacked-out, and the box used for light adaptation purposes is slid into place and turned on. We are using an intensity of 600 millilamberts for four minutes' duration, the subject being seated at 125 centimeters from the glare source. The subject is instructed to keep his gaze moving over the lighted area during the period of light adaptation.

At the end of four minutes, the glare-out box is removed, and the metal plate containing the stimulus area aperture is slid into place. We have used a  $1/3$  degree stimulus area in all our experiments so far. The fixation light is slid into the socket directly above the stimulus area, and readings of macular adaptation are taken every 30 seconds for the first five minutes.

The fixation light is then removed to the uppermost socket. With the subject viewing the red fixation light in this position, he will receive light

Fig. 1



Rheostat by means →  
of which the subject  
controls the intensit  
of the fixation light

Subject wearing BLB Aviation mask sitting in  
position in the low pressure chamber.

Fig. 2

Box with light adaptation source which slides over the window of the low pressure chamber

Metal plate with opening in lower part to carry stimulus area

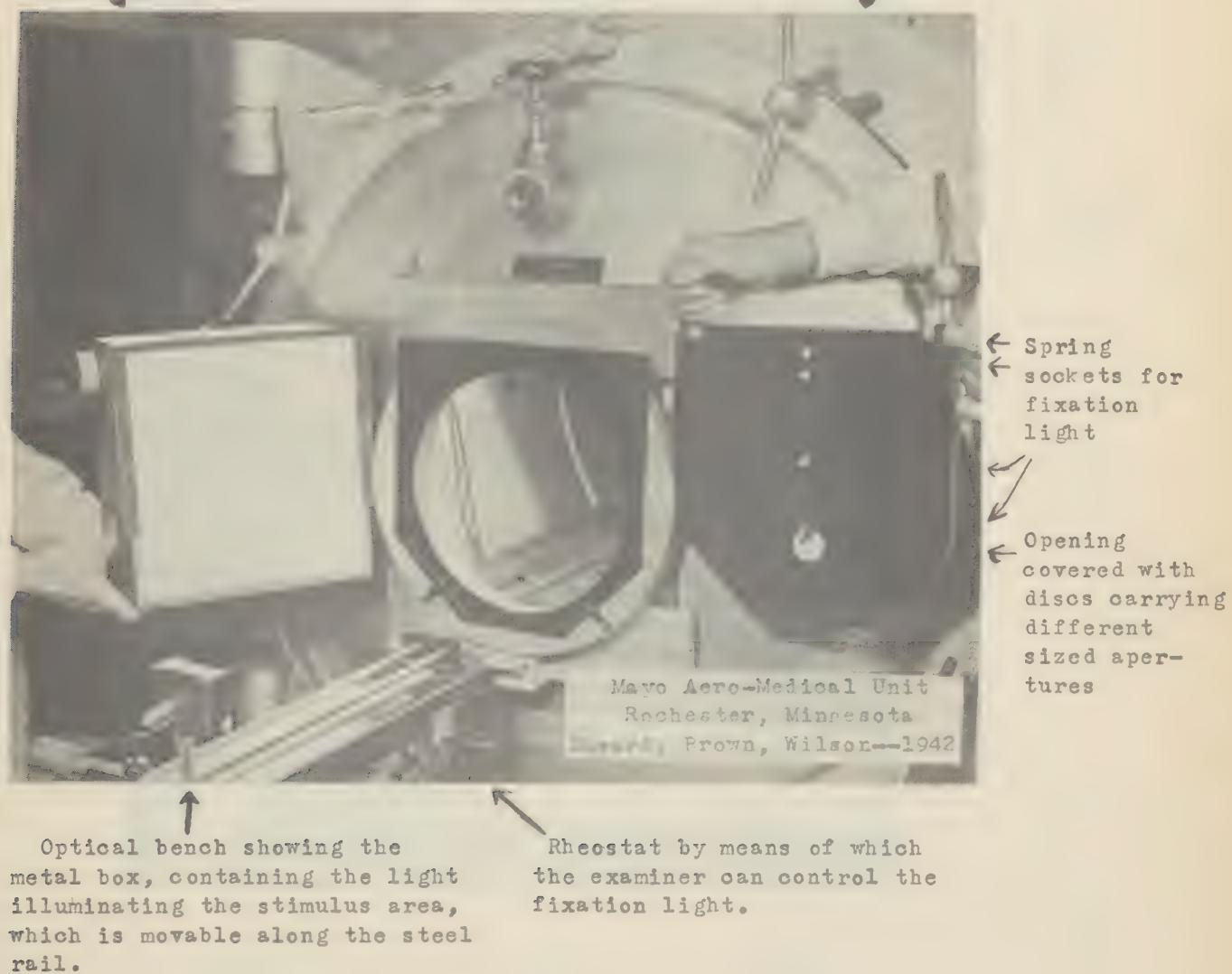


Fig. 3



Optical bench in position as used during the tests. The fixation light is shown in position in the uppermost socket of the metal plate, so readings of dark adaptation may be taken in a retinal area located  $10^{\circ}$  paramacularly.

from the stimulus area with that portion of this retina which is situated 10 degrees paramacularly. We have used this location for all determinations of paramacular dark adaptation made thus far. Paramacular readings are taken every thirty seconds until the readings appear to be leveling off. Then, in order not to unduly tax the subject, we usually take a reading every minute, followed immediately by another check reading. In this way, the subject can close his eyes and relax for 45 seconds between readings. Determinations of paramacular adaptation are continued until the end of 25 minutes in darkness, at which time the peripheral dark adaptation has reached a fairly constant level for the purposes with which we are concerned.

We then return the fixation light to its first position, and take 6 to 10 readings of the final macular level of adaptation.

At the conclusion of the test on dark adaptation conducted while the subject is breathing air, the light adapting source is again fixed in place over the chamber window and the second course of dark adaptation is commenced, but oxygen (instead of air) is supplied to the subject from the time the second glare-out was instituted.

#### C. Air and oxygen supply

The subject wears a 3 turret B.L.B. aviation mask at all times. During the first experiment of each series, the sponge rubber discs are removed from the mask, so that the subject can breathe the chamber air freely. No oxygen is supplied to the mask, of course. By removing these discs, there is no possibility of building up any excess concentration of carbon dioxide in the bag of the mask. We have the subjects wear the mask at all times, i.e., even during the tests with air, so that there will be the same amount of inconvenience, if any, from the mask during both the test with air and the test run while breathing oxygen. Hence, from this standpoint, all conditions are constant during any experiments in which air and oxygen respectively are used, except that the subject breathes pure oxygen during the second of the two tests.

At the time the second glare-cut period is to be started, the subject is instructed to replace the discs in his mask. When this is done, the oxygen flow is turned on (controlled outside the chamber) to 11 liters per minute and then the period of light adaptation is begun.

We have used a constant flow of 11 liters of oxygen per minute (measured outside the low pressure chamber) because this is sufficient to furnish any subject, regardless of weight, as nearly 100 per cent oxygen as it is possible to obtain.

As will be noted from the legends on the charts in Section II on the effects of anoxia, some of the earlier experiments were started without oxygen, and after the paramacular adaptation has leveled off, oxygen flow to the mask was turned on. After an apparent level was reached with oxygen, it was discontinued, and the level with chamber air again determined.

#### D. Consideration of pupil size

We have not attempted to control pupil size in our determinations, and we have had the subject use both eyes at all times. While such a method might not be approved in strictly clinical investigations, it seemed most desirable for the purposes at hand.

We were interested only in determining the dark adaptation levels of a group of young men of Air Corps age under conditions such as they would encounter when flying. If such men were flying at night, they would of course be using both eyes, and their pupillary diameters would become as large as possible in total darkness.

Pupillary reactions to light and to accommodation were normal in all our subjects. With the exception of one red-green blind subject (results not reported here) all subjects had normal (20/20 or better) acuity, had negligible refractive errors and possessed ample amplitudes of accommodation and of convergence.

## II. Effects of Anoxia

Tests run during January and February, 1942

Total tests - 77  
Number of subjects - 8

Dark adaptation tests made during this period were run at altitudes from ground level to 42,000 feet. Tests conducted at altitudes from ground level (1000 feet here at Rochester, Minnesota) to altitudes of 18,000 feet were done both with air and oxygen. Tests made at altitudes above 18,000 feet equivalent were always done with an adequate oxygen supply to the mask.

The course of dark adaptation was determined at various times during the day. During this period (January-February, 1942) no records were kept of basal metabolic rates of the subjects at the time of the investigations, since we did not know at that time what influence differences in B.M.R. would exert on the subject's ability to dark adapt.

Our experiments, however, show definitely that the dark adaptation levels of all subjects tested were much improved at all altitudes when they were breathing oxygen, when comparison is made to the levels obtained when breathing air.

We are attaching to this report three charts, Fig. 1 (A, B and C), showing the courses of dark adaptation obtained on the same subject. The uppermost chart (A) illustrates the results of a test at 5000 feet altitude. Even at this low atmospheric level there is a definite lowering of the threshold levels (therefore indicating better ability to see in the dark) when oxygen is breathed. When the oxygen is turned off, it takes only two to three minutes for the curve to rise again, indicating a reduction in the ability to dark adapt. The addition of oxygen at the end of thirty minutes in darkness once more causes an improvement in the final threshold level of ability to see in the dark.

The middle chart (B) illustrates the course of dark adaptation obtained at 10,000 feet altitude. Here there is shown a much more pronounced improvement in the ability to dark adapt upon the addition of oxygen.

The lower chart (C) shows the curve obtained at 18,000 feet altitude and shows the marked advantage in the use of oxygen as compared with air at such altitudes. In this subject there is demonstrated a three- to fourfold improvement in levels when oxygen is used.

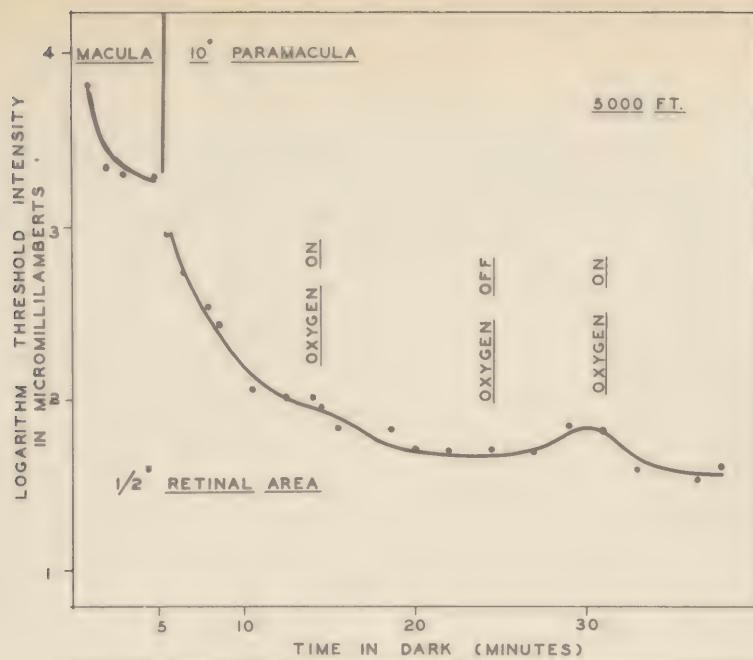


Figure 1 A

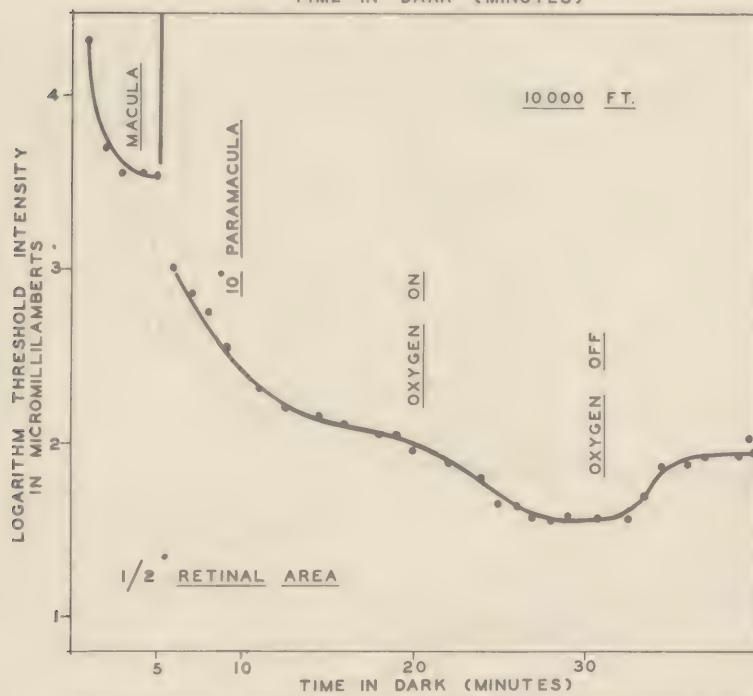


Figure 1 B

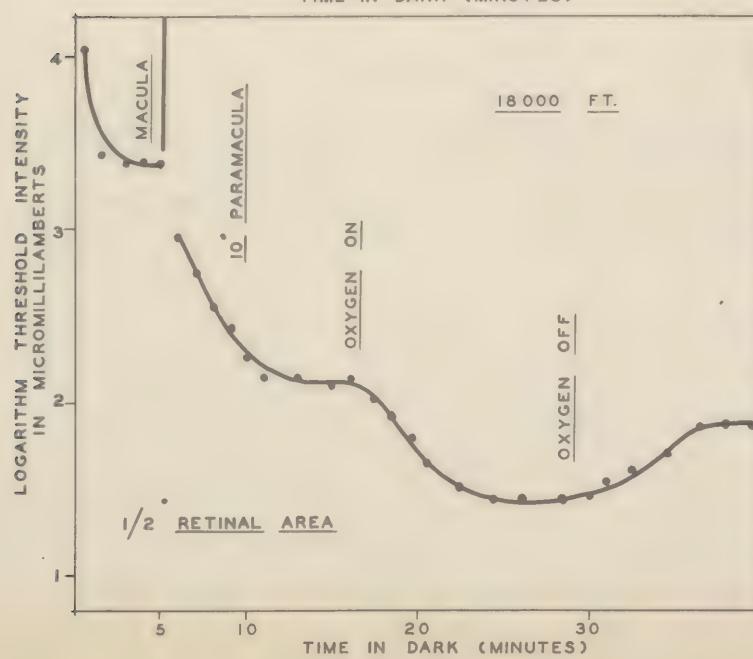


Figure 1 C

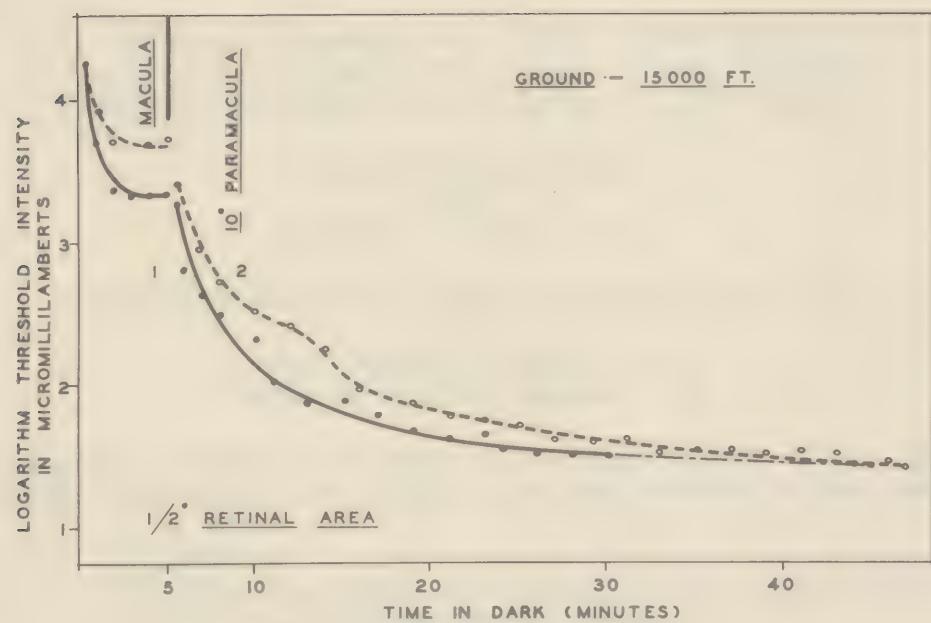


Figure 2

Curve 1 --- with air at ground level (1000 feet)

Curve 2 --- with air at 15000 feet simulated altitude

Figure 2 shows two sets of dark adaptation data obtained on successive runs. The solid black curve shows the results obtained at ground level, and the dotted line curve the data obtained at 15,000 feet altitude. As may be noted in the data obtained at 15,000 feet equivalent altitude, lack of oxygen slows or decreases the rate of dark adaptation as well as causing final (20-30 minutes' readings) higher thresholds than are obtained with oxygen.

In this particular experiment, readings were obtained for nearly 50 minutes while the subject was at altitude, but for only 30 minutes when he was at ground level. It might be judged that a projection of the curve at ground level (broken line portion of Curve 1) would meet the curve obtained at altitude, as shown in the graph. However, many subsequent test runs have proved to us that this is not always true. The final levels (20-30 minute period) of dark adaptation at altitude are always higher, even at the end of one hour of testing, than they are at ground level or when the subject is using oxygen in altitude tests.

### III. Effects of Fasting and of High Carbohydrate Meals on the Courses and Threshold Values of Dark Adaptation Obtained at Ground Levels, Using Air and Oxygen

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and  
Kenneth G. Wilson, M. D.

Data obtained during March, April and May, 1942

Total number of tests - 118  
Number of subjects tested - 15

The purposes of these tests were to demonstrate the effects of air and oxygen on the dark adaptation levels which are reached in the same subjects

- a) Fasting
- b) After the subsequent ingestion of a high carbohydrate meal
- c) With the added factor of fatigue

Our previous data on the courses of dark adaptation (see Section II) obtained at both ground level and at various altitudes showed variations from day to day in the final (20-30 minutes) level on any one subject for which we could not account. The difference in final level in any one subject varied from 0.1 to 0.6 log unit (1.25 to 4-fold) on different days.

In an attempt to check the factors which might possibly influence this daily variation in levels, we decided to study the effects of metabolic changes on dark adaptation levels.

We rechecked all subjects under fasting conditions at ground level, the first test being made when the subject was breathing air, followed immediately by another test with the subject breathing oxygen. Although the final levels (20-30 minutes' data) while breathing air varied as much as they had in our previous investigations, we found that the final levels obtained with oxygen did not vary more than 0.1 log unit on different days. Frequently the variation was as little as 0.05 log unit.

In our earlier work, we had not given consideration to the amount and type of food the subject had eaten prior to the test. The tests on fasting subjects seemed to indicate that an investigation of the effects of fasting and of food intake might be of some importance. We decided to make dark adaptation tests on all subjects at the same hour each morning subsequent to a fast from 7 p.m. the night before. Hence all the tests made in the morning were started between 9 and 10 a.m. Upon completion of the experiment, all subjects were given the same high carbohydrate meal at noon time. This meal contained 240 grams carbohydrate, 10.5 grams protein, and 9.5 grams fat. The food consisted of sweetened fruit juice, sliced grapefruit with sugar, oatmeal with sugar, 1 glass milk, and 6 pieces of stick candy to be eaten after the meal. We decided on this type of meal because it could be duplicated easily and would be practical to use in the Air Corps if it seemed to be beneficial.

The second series of tests, again using air first to be followed with oxygen for the second test, were run at 3 to 4 p.m. Prior to both the morning and afternoon tests, we determined the subject's basal metabolic rate, respiratory quotient, blood pressure, pulse, respiration rate, and temperature. Any abnormality in the amount of sleep the previous night was also recorded.

In fasting subjects, oxygen not only increased the speed with which dark adaptation occurred, but showed much lower final (20-30 minutes) threshold levels than were obtained when the subject was breathing air. Furthermore, the curves obtained on any given individual when breathing oxygen were remarkably constant from day to day.

Data obtained on subjects after the ingestion of high carbohydrate meals showed that the curves of dark adaptation were nearly the same, both as to rate and final level of adaptation, when the subjects breathed either air or oxygen. However, there was a slight advantage in the use of oxygen.

In a very limited number of instances we have found that fatigue due to loss of sleep the night before the tests superimposed on a 12 to 14 hour fast raises the level of adaptation to a remarkable degree. Oxygen, in cases of fatigue, greatly improves the ability to see in the dark. The ingestion of a high carbohydrate meal by a subject who is breathing air at ground levels produces thresholds of dark adaptation which are slightly better (see Fig. 2) than are obtained when the subject is fasting and breathing 100 per cent oxygen.

While the graphs shown in this section depict the results of tests on one subject only, they are representative of the curves obtained on all the subjects used. Graph No. 2 was obtained after the subject had had only two hours' sleep the previous night. Graph No. 3 was obtained the day after Graph No. 2, when the subject had slept twelve hours the night before the tests. Graph No. 3 shows that the difference between the dark adaptation values (two lower curves) obtained in the morning on the same fasting subject breathing air and oxygen respectively is less than found on other occasions (Fig. 2). A likely explanation is that the subject was as completely rested as possible, and the tests were made two hours after he had awakened. During the day, the subject continued his fast and carried on his regular work in the laboratory between the periods of the morning and afternoon tests. The upper curve in Graph No. 3 was obtained in the later part of the afternoon and indicates that the slight fatigue which occurs during a day of normal office work without breakfast is enough to raise the threshold of dark adaptation. The basal metabolic rate was the same both in the morning (-11 per cent) and in the afternoon (-12 per cent).

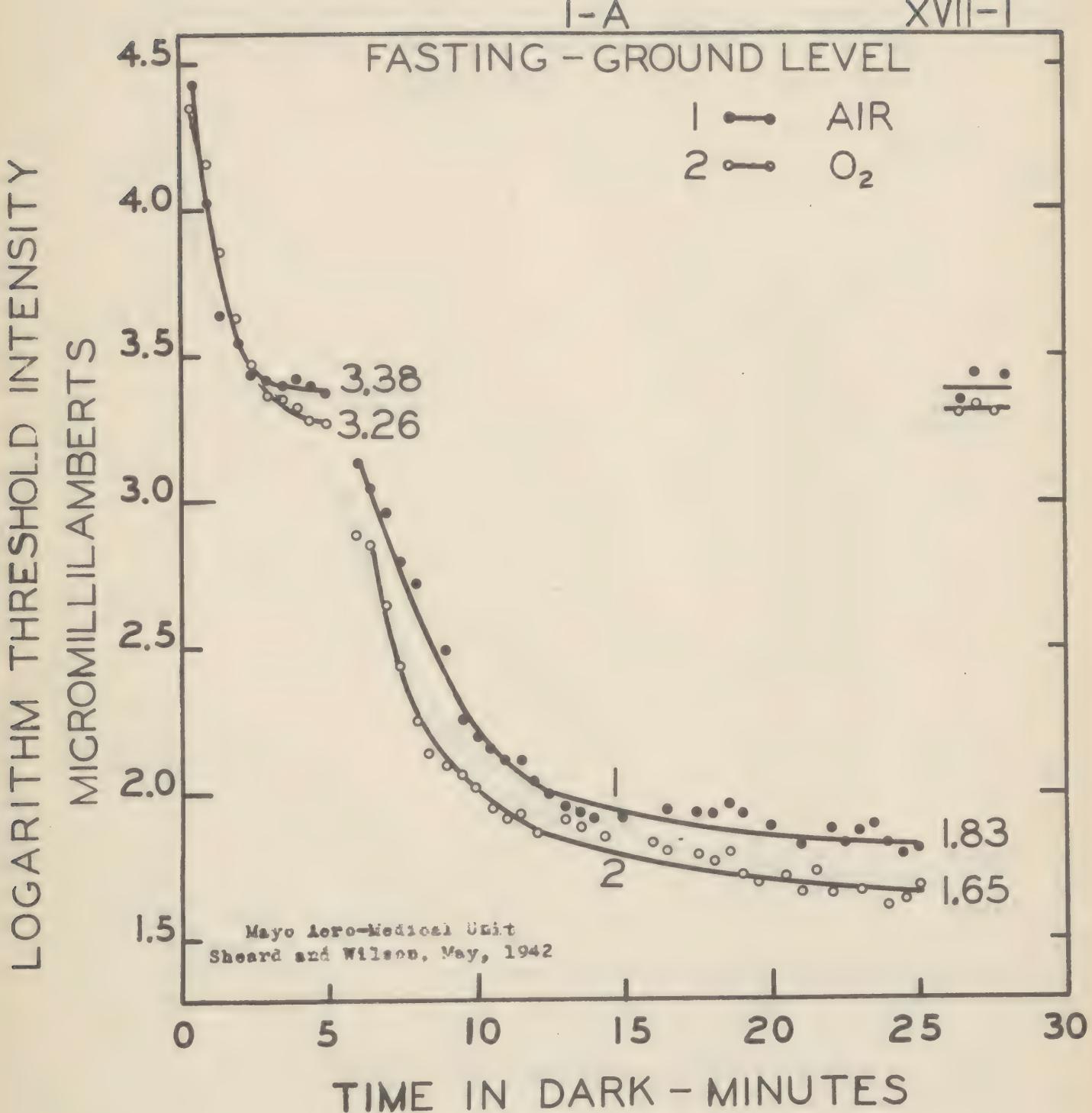


Fig. 1 A: The subject breathing oxygen is able to see with macular vision a light 30 per cent less in intensity than can be seen while breathing air.

Paramacularly, with oxygen, a light 50 per cent less in intensity can be seen than could be seen while breathing air.

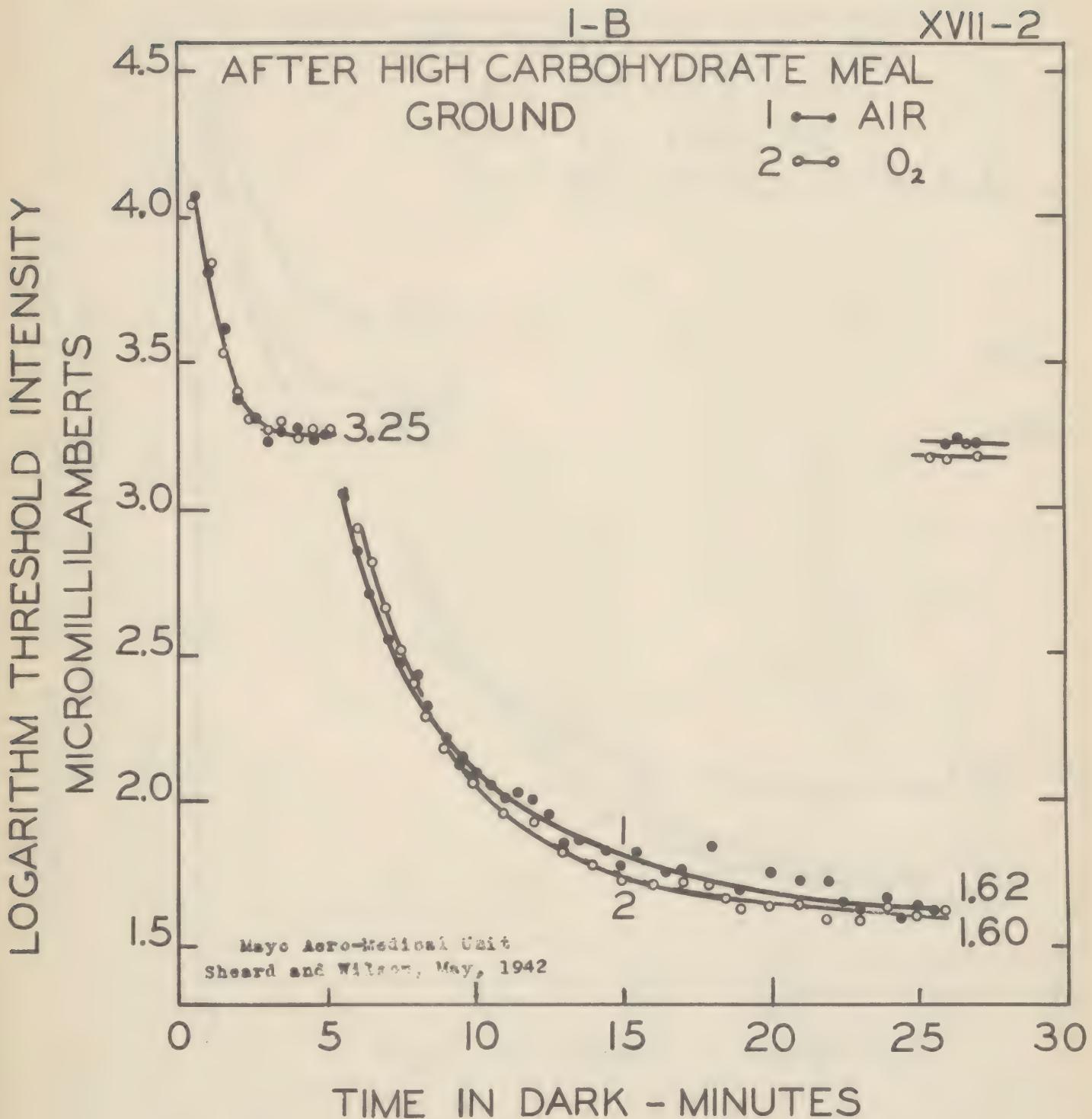


Fig. 1 B: This graph shows the results obtained in the afternoon on the same subject as in Fig. 1 A.

After a high carbohydrate meal, the curves with air and oxygen are practically the same, although even here there is a slight but definite improvement with the use of oxygen.

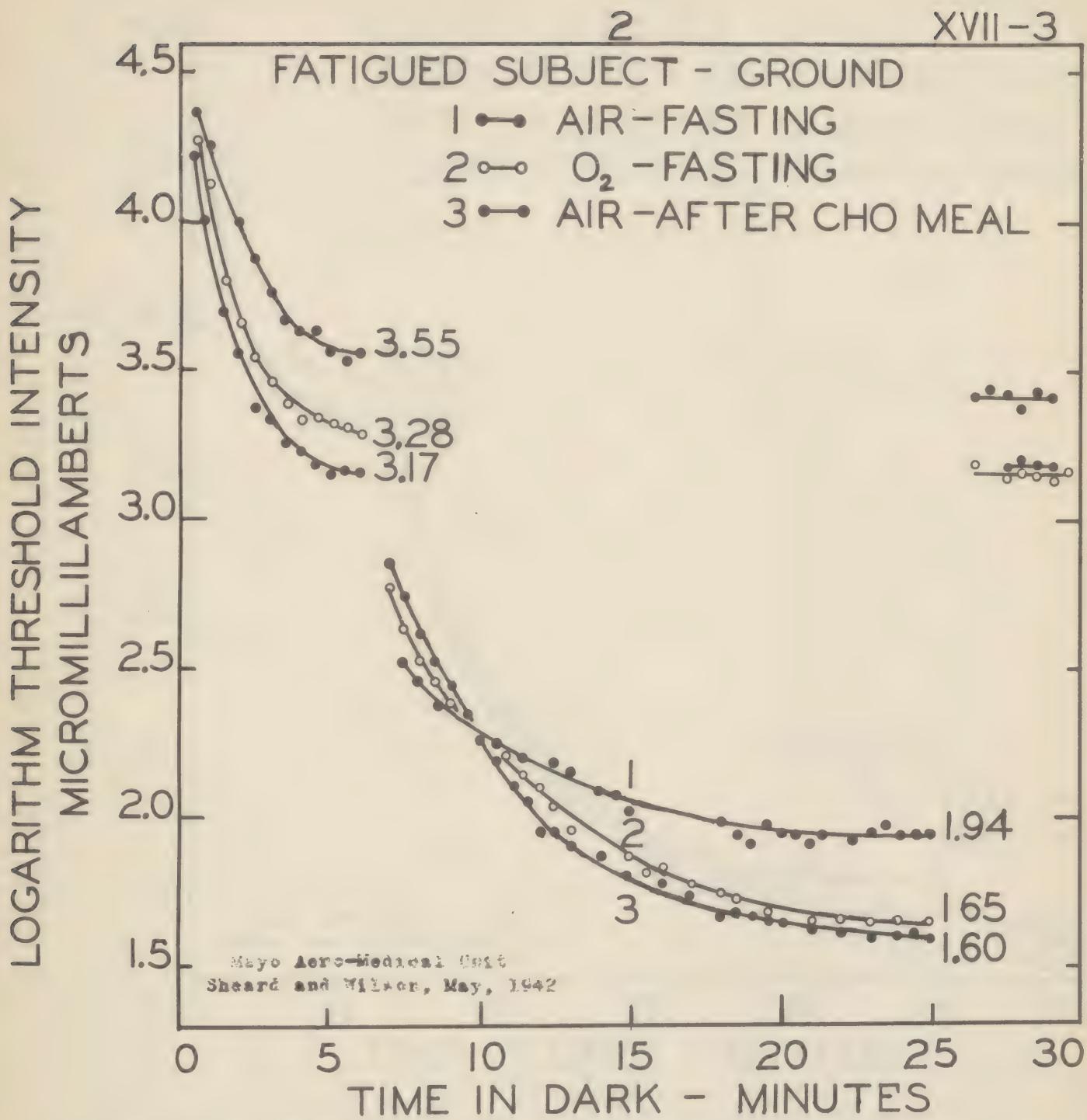


Fig. 2 illustrates curves obtained on the same subject as in Figs. 1 A, 1 B, and 3. In this instance the subject had only two hours' sleep the night before the tests.

As seen in curve 1, the levels obtained with air are considerably higher than any others obtained on this subject in 18 tests. Oxygen (curve 2) enabled the subject to see a light 54 per cent less in intensity with his central vision and 66 per cent less intense a light paramacularly than he could see while breathing air.

Curve 3, obtained after the subject had the high carbohydrate meal, shows that the subject can see a light 66 per cent less in intensity at the macula than he could see when fasting. He sees paramacularly a light 70 per cent less in intensity than could be perceived while fasting.

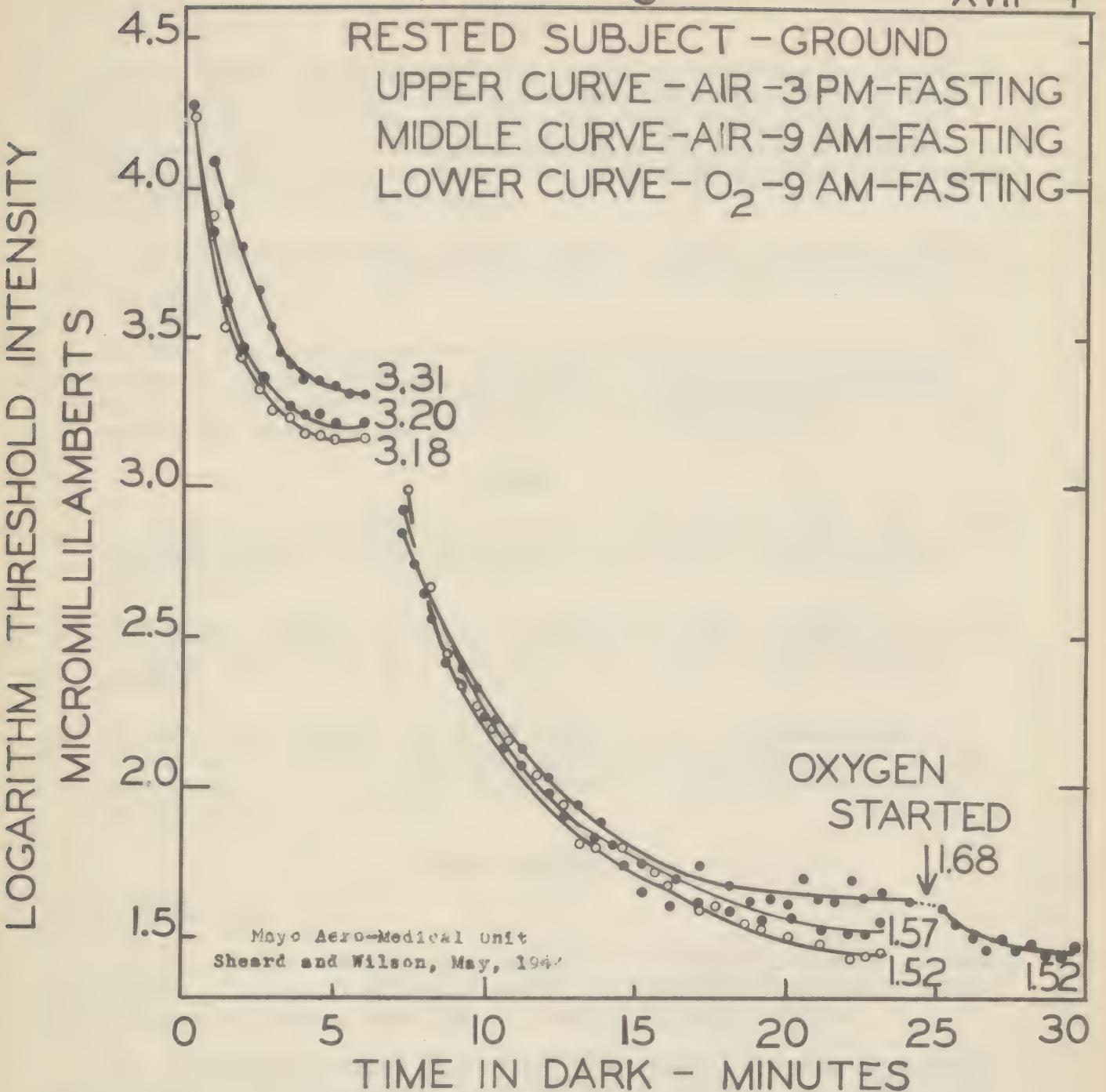


Fig. 3 was obtained while the subject was completely rested after a 12 hours' sleep the night preceding the experiment. In this case, the subject fasted all day. The upper curves were obtained in the afternoon, while the middle and lower curves were obtained in the morning.

As may be noted, there is only a slight variation here between the middle curve obtained with air and the lower curve obtained with oxygen in the morning. This appears to indicate that a completely rested person, even though fasting, is able to reach nearly as good a level of dark adaptation while breathing air at ground level as when breathing oxygen.

The upper curve was obtained at 3 p.m. while the subject continued his fast from the previous evening. Some effect of fatigue appears now to be acting upon the subject, for the final level of both curves (macular and 10° paramacular) is higher than in the morning. Administration of oxygen at the end of 25 minutes brought the dark adaptation to lower levels, however, within four minutes' time, indicating that the subject could see as well in the dark (in spite of more fatigue) as he could in the morning when he was breathing oxygen.

### Discussion

Anoxia, hunger and fatigue all play a role in decreasing the ability of aviators to see in the dark. Even at the moderate altitude of 1000 feet above sea level (which is ground level at the Mayo Clinic, where these studies were made), in order that an individual may attain his maximum ability to see in the dark he should eat a meal high in carbohydrate content and be breathing 100 per cent oxygen.

Our results show that the ability to see in the dark decreases with increases in altitude as a result of progressive anoxia, excessive fatigue, or lack of adequate food.

Our data show that an observer, having complied with these two requirements (namely, oxygen and food), even though fatigued and flying at any altitude, will be better equipped to become as quickly adapted to the dark as possible and to attain his best levels of dark adaptation.

### Summary

1. In fasting subjects, there is a definite improvement in the dark adaptation level obtained while breathing oxygen over that obtained while breathing air.
2. In fatigued subjects, there is an even more decided advantage in the use of oxygen as compared to air in the final levels of dark adaptation obtained.
3. The amount and type of food eaten prior to dark adaptation tests profoundly influence the final level attained. A light meal of very high carbohydrate content appears to be quite effective in increasing the ability to see in the dark.

### Recommendations

It is recommended

(1) That flight crews on night missions be required, whenever possible, to make use of oxygen from ground levels, and to continue the use of oxygen until return to ground, especially if landing is made at night.

(2) That the crew shall be provided with light (not bulky) high carbohydrate meals (approximately 1000-1200 calories) about an hour before take-off time. It is further recommended that, if the flight is to last for five to six hours or more, the crew be provided with concentrated carbohydrate food for ingestion while enroute.

(3) That flight crews be impressed with the necessity of adequate rest before any flight is undertaken.



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Report: Series B, No. 2

Date: 14 September 1944

ON THE TRANSMISSION OF RADIANT ENERGY (VISIBLE AND ULTRAVIOLET) BY MATERIALS  
SUBMITTED. Report by Charles Sheard, from the Mayo Aero Medical Unit, Rochester,  
Minnesota.

Summary

Various samples of material, which would be commonly referred to as cloth, have been tested in regard to their transmissive properties for visible and ultraviolet radiation. All tests by various physical and optical methods or of a biological character indicate that the order of transmission of the samples is (1) blue, (2) olive drab and (3) dull gold as designated by color. In general, the more porous the material or greater the area of apertures, the greater the transmission of visible and ultraviolet radiation.

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INTRODUCTION

Samples of the material were tested as to their transmissive properties in the visible and ultraviolet regions. The materials are referred to by color designation as (1) blue, (2) olive drab and (3) dull gold. The tests were made by various spectroscopic, spectrophotometric, photelometric (using photoelectric cells), fluorescent and biological (erythematous) methods and measurements.

DATA AND CONCLUSIONS

I. Incandescent lamp (ordinary 60 watt lamp) as source of radiation; photoelectric cell and suitable ammeter. Percentage transmissions (1) blue, 25%; (2) olive drab, 16% and (3) dull gold, 24%.

II. Sunlight as source of radiation; photoelectric cell and suitable current measuring instrument. Results were (1) blue 17%, (2) olive drab 10%, (3) dull gold 16%.

III. Incandescent lamp, using Sheard-Sanford Photelometer.

- a) Without the use of infra-red absorbing filter, the data were in the same order as given in divisions I and II.
- b) With infra-red absorbing filter, transmissions as recorded by instrument were (1) blue 35%, (2) olive drab 30%, and (3) dull gold 20%.

This last (III) set of data, making use of the ordinary block-layer type of photoelectric cell (as manufactured by General Electric, Weston or Westinghouse) and employing an infra-red absorbing filter (since such types of photolect cells are influenced by near-red radiation), is the most accurate of the three groups of measurements insofar as visible and ultraviolet transmission are concerned.

IV. Quartz Mercury Arc as source of illumination; photoelectric cell and recording meter. Data obtained showed that transmissions of radiant energy from such a source were: (1) blue 22%, (2) olive drab 16%, and (3) dull gold 9%.

V. Quartz Mercury Arc as source and Fluorescent screens as detectors. Very simple and satisfactory fluorescent screens made of cardboard or filter paper and dipped or coated with a solution of fluorescein were used. The distance of test could be varied and degree of fluorescence estimated. The data obtained were in excellent agreement with No. IV. In a summarization of results of various tests involving fluorescence (hence a measurement of ultraviolet transmission by various materials), the order is: (1) blue, maximal transmission; (2) olive drab next and closely approximating sample 1, and (3) dull gold as a minimal.

VI. Biological or Erythematous Results. A suitable metallic sleeve was used; in this sleeve several one-inch holes were cut and covered with samples of the three materials, respectively. Several individuals were used and dosages varied until a very mild erythema could be developed and observed under one or more of the samples. Exposures of the inner aspects of the lower arm were made in general. Areas covered with the three materials, respectively, were exposed simultaneously, thereby eliminating various physical and biological variants. The order of time of appearance of erythema and degree of erythema were the same in all subjects tested, namely: (1) blue, (2) olive drab, slightly and in some subjects somewhat definitely delayed in time of appearance and degree of erythema, and (3) dull gold. In the last instance (dull gold) there was no indication of biological action of the radiation from the quartz mercury arc on the skin, although definite erythema was shown with (1) and (2). These data are in agreement with the findings given under IV and V.

In general terms, of course, it can be said that, all other factors remaining the same (such as thread materials, weight of stock and so forth), the transmission of radiant energy would be proportional to the total area of openings (or holes) in the material. The greater the porosity, the greater the transmission as a general rule. However, color of material exercises an effect, in that spectral distribution of the light source and of the light reflected from the materials must be considered. Therefore the writer believes that the ultra-violet transmission of such porous materials will be affected chiefly, if not wholly, by relative area of apertures.





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